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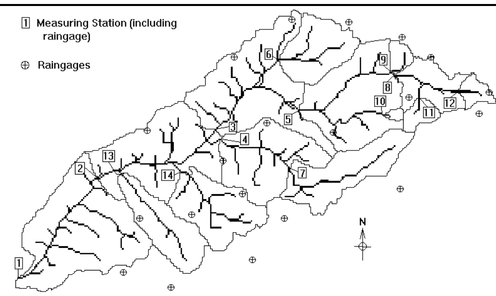

Documentation of Hydrologic, Geomorphic, and Sediment Transport Measurements on the Goodwin Creek Experimental Watershed, Northern Mississippi, for the Period 1982-1993 -- Preliminary Release

William A. Blackmarr, Editor

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Chapter 1

INTRODUCTION

1.1 Historic Background

Land erosion is a problem that is confronted everywhere in the United States. In particular, many streams and rivers throughout the country experience severe degradation problems associated with bed incision and streambank erosion. In 1978, the U.S. Army Corps of Engineers (COE) estimated that there were 142,000 miles of stream channels experiencing serious bank erosion in the United States, and 575,000 miles of less severe erosion resulting in annual losses of about $270 million. The estimated annual costs of streambank protection were $870 million. Nowhere in the country is land erosion and its deleterious effects more prevalent than in the Lower Mississippi Valley, especially within the foothills region of the Upper Yazoo River Basin. Erosion rates in the area are nearly double that of the national average.

The early European settlers rapidly developed the highly productive and fertile soils within the Yazoo Basin, but with little or no attention to conservation practices. Soon, the main channels were plugged with sediments while tributary channel banks and bottoms were degraded. Upland gullies were formed and erosional processes were accelerated. To combat these ever increasing problems, drainage districts were formed during the period 1880-1940. The districts attempted to implement some erosion control remedies, but because they usually focused on site specific problems, the district's projects often did little to alleviate basin-wide problems and sometimes aggravated the existing erosion problems. After 1940, the COE and the USDA Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service) led various activities to control erosion, reclaim land, improve drainage, and reduce flood damages caused by erosion and sedimentation.

1.2 The Section 32 Program

The magnitude of economic losses associated with stream bank erosion caused the Congress of the United States to pass the River and Harbor Act of 1968. Title 1, Section 120 of this Act (Public Law 90-483) directed the Corps of Engineers (COE) to "make studies of the nature and scope of damages which result from streambank erosion throughout the United States...." The ensuing Report (U.S. Army Corps of Engineers, 1969) appraised annual damages at approximately $90 million and annual cost of conventional bank protection required to prevent damage at about $420 million. The 1969 Report concluded that "... a substantial research program is needed to develop cheaper and more effective methods of treatment. Such a program should also include efforts to improve our understanding of the mechanics of stream channel behavior and bank erosion...."

As a result of the 1969 COE Report, the River and Harbor Act of 1968 was followed by the Streambank Erosion Control Evaluation and Demonstration Act of 1974 (Section 32, Public Law 93-251) amended by Public Law 94-587, Section 155 and 161. This legislation authorized a five-year program consisting of an updated analysis of the extent and seriousness of streambank erosion, research studies of soil stability and hydraulic processes to identify causes of erosion, and evaluation of existing bank protection techniques, and construction and monitoring of demonstration projects to evaluate the most promising bank protection methods and techniques.

To accomplish the objectives of the authorizing legislation, a steering committee developed a program consisting of the following Work Units:

(1) Evaluation of extent of streambank erosion, nationwide.
(2) Literature survey and evaluation of bank protection methods.
(3) Hydraulic research on effectiveness of bank protection methods.
(4) Research on soil stability and identification of causes of streambank erosion.
(5) Ohio River demonstration projects.
(6) Missouri River demonstration projects.

(7) Yazoo River Basin demonstration projects.

(8) Demonstration projects on other streams, nationwide.

(9) Reconstruction at demonstration projects.

(10) Reports to Congress.

Status of the programs in each of the work units was reported in an Interim Report to Congress in September 1978 (see U.S. Army Corps of Engineers,1978). This Report was used to estimate the losses associated with streambank erosion and costs of protection previously listed. The updated estimates show nearly a 100 percent increase between 1969 and 1978.

The Yazoo River basin of Mississippi has been a source of problems for many decades, with excessive erosion and bank instability necessitating costly counter measures both in the hills and in the downstream Delta area. Hill stream degradation has resulted in land loss, bank caving, and damage to highway bridges. Many streams have enlarged to the extent that 50 to 100 year runoff events are contained with banks. Aggradation downstream is caused by lower channel slopes in the Delta. This results in flooding and loss of navigation. The demonstration project is directed toward determining the causes of stream instability, whether chronic or acute, and toward determining ways to best work with natural controls, so as to develop the least expensive program to re-establish drainage basin stability. The project was designed to demonstrate the effectiveness of alternative bank revetment and stabilization practices, to identify soil stability problems and causes of erosion, and to make recommendations on means for the prevention and correction of streambank erosion.

The U.S. Army Corps of Engineers was charged with the implementation of this program. Many Districts coast to coast began to set up their evaluation and demonstration projects in 1976. In the Vicksburg District, a series of bed and bank stabilization measures and structures were planned by the U.S. Army Corps of Engineers. For some of these, a data collection and evaluation program was sub-contracted to the USDA-ARS, National Sedimentation Laboratory (NSL), Oxford, Mississippi.

To accomplish these tasks, the NSL had to (1) select watershed areas where stream channels exhibited both stable and unstable conditions, (2) design a research program around guidelines set forth in Public Law 93-251, (3) design bed and bank stabilization measures that would serve for both demonstration and research purposes and (4) evaluate the results of the above efforts throughout an indefinite period of time. In addition to the above, many other types of alternative bank revetment and stabilization practices were to be designed and installed by the Corps of Engineers. The NSL staff were to perform the evaluation phase of the study on these practices.

Public Law 93-251 stipulated that, in the Vicksburg District, the channel stabilization evaluation and demonstration project funds would be expended on bluffline streams and on streams tributary to the main rivers below the four main flood control reservoirs, Arkabutla, Sardis, Enid and Grenada. Since these impoundments trap most of the sediment entering them erosion above these lakes is no longer considered to be a contributing factor to the sedimentation problems in the main rivers below. A search for the study areas was begun in 1976. Areas were sought that, while having both stable and unstable reaches, had the greatest diversity of conditions that could be considered as pertinent variables in the natural processes affecting bed and bank stability. Four watersheds in the Yazoo River basin meeting these selection criteria for the project were Hotophia Creek, Long Creek, Tillatoba Creek and Goodwin Creek. Of the selected watersheds, Goodwin Creek was chosen to be the highly instrumented, nested set of sub-watersheds, in which most data would be collected. Fourteen combination grade control and flow gaging stations were designed for the area.

1.3 The Demonstration Erosion Control (DEC) Project

In 1984, the U.S. Congress authorized the DEC Project. The COE and NRCS were directed to work together to control the erosion, sedimentation, and flooding in the foothills region of the Yazoo River basin. The DEC Project is an intensive program designed to demonstrate the effectiveness of tools developed under the Public Law 93-251 Program to control erosion and sedimentation. The DEC Project is a joint effort among the COE Vicksburg District, NRCS, the USDA Agricultural Research Service (through NSL), and the U.S. Army Engineers Waterways Experiment Station (WES). The COE and NRCS serve as the two action agencies responsible for planning, design, and construction of project elements. The ARS and WES participate in an advisory capacity to support the overall mission and to provide pre- and post-project research, monitoring, and evaluation. Additionally, the U.S. Geological Survey (USGS) provides assistance through stream gaging on DEC streams. The watersheds mentioned in Section 1.2 are among the watersheds within the Upper Yazoo River basin that received authorization for DEC projects.

1.4 Need for an Experimental Watershed

One important phase of the work done by NSL for the COE Vicksburg District, in support of the Public Law 93-251 Program, required the establishment of an experimental watershed to test concepts developed in the study and provide data to verify models and components developed in the research. It was anticipated that grade control structures would be installed in the watershed and sufficient data collected to answer questions about the performance of the structures, water and sediment transport, the upstream factors affecting this transport and the influence of all of these factors on the channel system. The underlying idea for testing was: treatment of a reach by a structural measure wasn't independent of upstream influences or of other reach treatments. Hopefully, an integrated systems approach which considered the basin and upstream practices as well as combinations of structural measures could be developed. Thus, the purpose of the experimental watershed is to provide data needed to estimate the impact of upstream land use and watershed processes on sediment supply and transport in stream channels and how this affects channel stability. The data collected will be also used in the DEC project to develop and calibrate mathematical models needed to assess the long-term impact of DEC practices on sediment yield and flooding.

1.5 Selection Criteria

Watershed selection was based on four criteria: (1) location should be in the Bluff Hills draining to the Mississippi Alluvial Plain, (2) suitable for subdivision (sub-catchments) to meet the research needs of the cooperative study, (3) no drainage into an existing flood control reservoir; and (4) close proximity to the National Sedimentation Laboratory to allow effective guidance of the field research.

The Bluff Hills area is the location of much channel instability and sediment production problems, while the Mississippi Alluvial Plain is the area of aggradation which receives this sediment. Therefore, the first requirement is that the watershed be located in the Bluff Hills region draining into the Mississippi Alluvial Plain.

In Mississippi, the area known as the Bluff Hills (or Loess Hills) is a strip of land from 20 to 40 miles wide, east to west, stretching from the Tennessee state line near Memphis, along the eastern edge of the Mississippi Alluvial Plain (locally called the Delta), to near Vicksburg then along the Mississippi River to the Louisiana state line (Figure 1.1). The western edge of this region is generally well-defined where the loess hills drop abruptly to the alluvial plain. The loess surface mantle thins to the east where it blends into the North Central Hills (Cross, 1974). The depth of loess in places is close to 100 feet, although the deposits in the deeper areas are generally 30 to 50 feet in depth. The significance of this area for sediment research lies in the ready erodibility of the loess material when stripped of cover. Erosion of the material, Holocene valley sediments, has produced deeply incised channels in the tributaries, which have dissected landscape of the Bluff Hills. Most of the channels have steep sides which are unstable, contributing additional sediment and causing loss of adjacent agricultural land and habitat. Figure 1.2 shows the general soils map of Panola County, the area where the research watershed was established. The two dominant soil associations are the Loring-Grenada-Memphis soils of the uplands and the Collins-Falaya-Grenada-Calloway soils of the valleys which cover most of the county. The Loess Hills is a significant problem area locally and is similar to other problem areas of the United States. This similarity means findings from research in this region should have applicability in other areas.

The second selection criteria required suitability for the research needs of the cooperative study. This included several characteristics. One is diversity of land use, channel type and sediment source area. This diversity was sought to increase the amount of information that could be extracted from the field research. A watershed with primarily one type of land use might not answer questions about the effects of other types. If sediment source areas and channel types were unrepresentative in character, this information extraction would be more limited. Another characteristic was access by roads, while another was the presence of a good reach for routing.

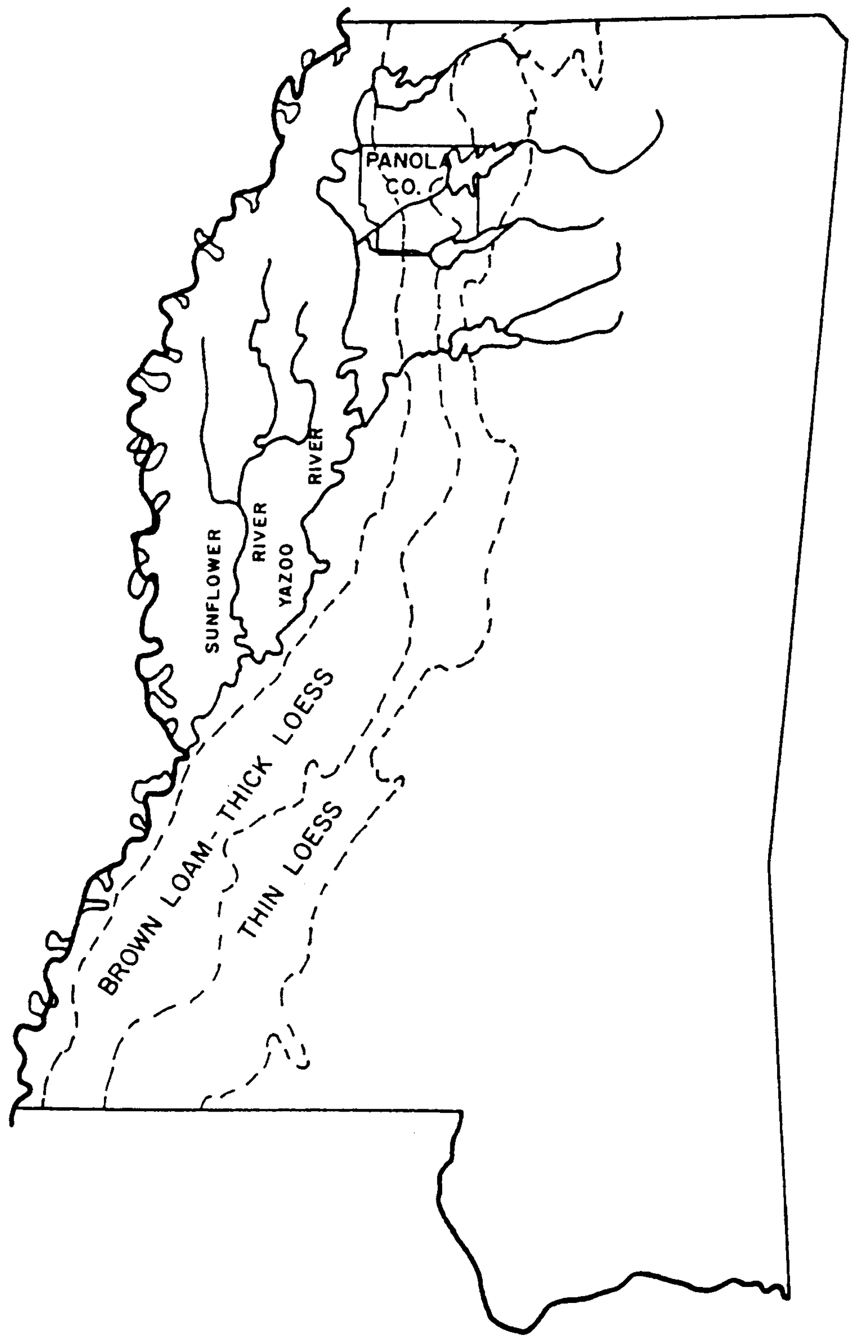


Figure 1.1 Location of Loess Hills Land Resource Area in Mississippi

A third criteria required location of the watershed on a stream that did not drain into one of the existing flood control reservoirs. This was a requirement of the plan of study developed under Section 32 of Public Law 93-251, "Streambank Erosion Control Evaluation and Demonstration Project".

The fourth criteria required proximity of the watershed to the research headquarters in Oxford, Mississippi. Field research must be guided from the central laboratory. The further away the watershed is, the more costly and less effective the guidance will be. Since many trips to the watershed are required, minimizing the travel costs are important. A one-way travel time of 30 minutes to a hour was considered acceptable.

As a result of these criteria, search for the watershed was concentrated in the area shown in Figure 1.3. This area, in southeast Panola County, lies between Sardis Reservoir and Enid Reservoir. Oxford is located 9 miles east of the Panola-Lafayette County line on Highway 6. Some searches in areas north of Sardis Reservoir and below Enid Reservoir were made but these areas were rejected because of distance from the central laboratory which would have to be traveled. The choice finally was narrowed to Long Creek or Hotophia Creek or one of their tributaries. Extensive reconnaissance was made in the field and Hotophia Creek was eliminated due to the limited diversity of land use.

In Long Creek, several tributaries of the watershed were considered, but later eliminated. Hurt Creek had poor road access and limited diversity. Johnson Creek had a long channel with no major tributaries. However, Johnson could not be subdivided to create areas of different land use. Long and Caney Creeks were primarily timbered with little agricultural land and had numerous gullies, which would likely bias the results of a study. Goodwin Creek had the best combination of access, diversity of land use, diversity of sediment source areas and channel conditions. Thus, Goodwin Creek was finally selected as the experimental watershed. This watershed meets the selection criteria and, in addition, it exhibits excessive upland erosion, steep degrading channels, loss of land due to channel bank caving, and downstream deposition problems, all of which are characteristic of many watersheds throughout the mid-continental and southeast sections of the United States.

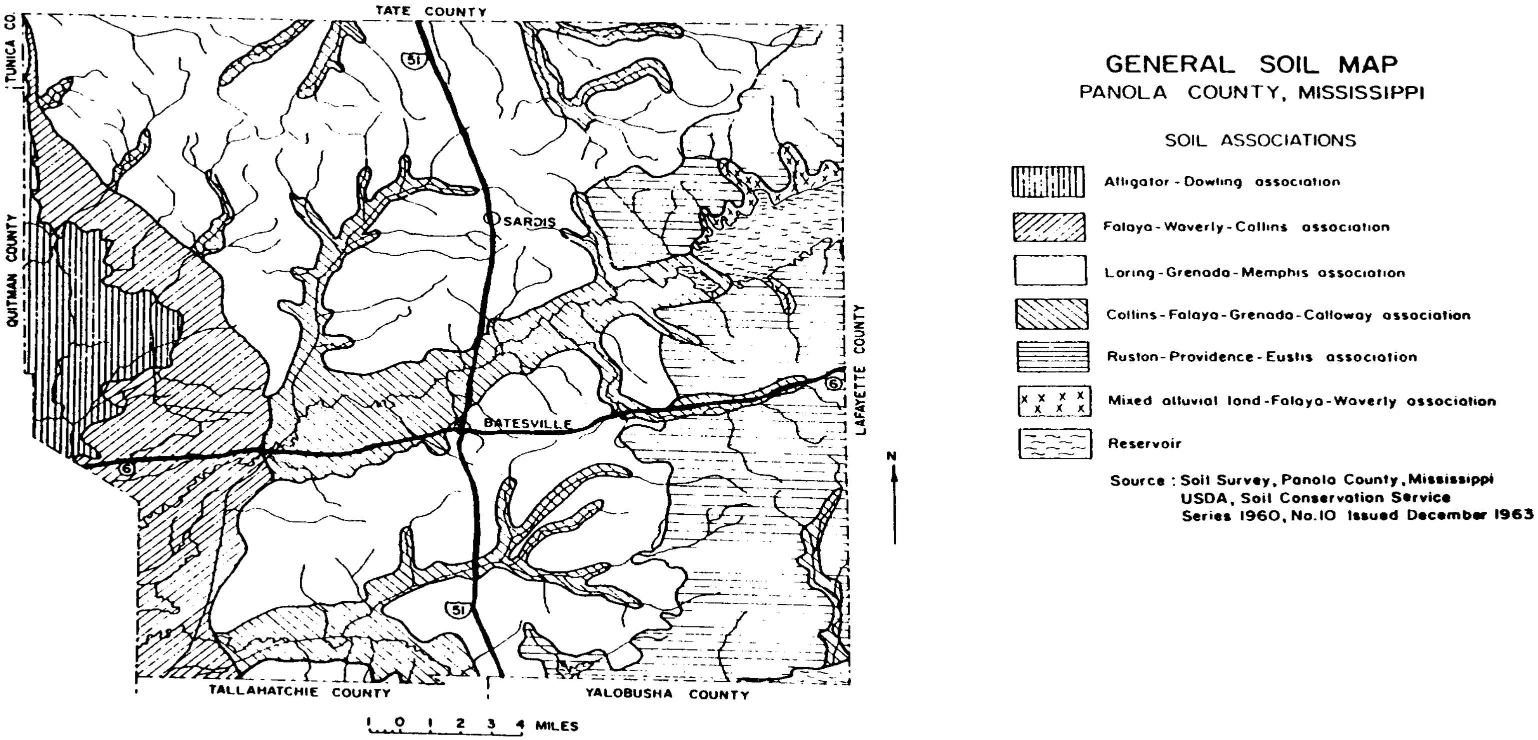


Figure 1.2 General Soils Map of Panola County, Mississippi

1.6 Brief Overview of the Goodwin Creek Watershed Project

Goodwin Creek is a tributary of Long Creek which flows into the Yocona River, one of the main rivers of the Yazoo River Basin. The Goodwin Creek Watershed location and its boundary are shown in Figure 1.3. The COE, Vicksburg District, provided much of the construction funds when this watershed was originally established in 1977. The watershed is operated by the NSL, and it is organized and instrumented for conducting extensive research on upstream erosion, instream sediment transport, and watershed hydrology.

The Goodwin Creek Watershed is divided into fourteen nested subcatchments with a flow measuring flume constructed at each of the drainage outlets. The drainage areas above these stream gaging sites range from 0.63 to 8.26 square miles. Twenty-nine standard recording rain gages are uniformly located within and just outside the watershed. Instrumentation at each gaging site includes and electronic data acquisition system which consists of a VHF-radio telemetry system with microcomputer. This system collects, temporarily stores and transmits the data at predetermined intervals to a central computer at the National Sedimentation Laboratory. A detailed account of the watershed operation is presented in Chapter 2.

The climate of the watershed is humid, hot in summer and mild in winter. The average annual rainfall during 1982-1992 from all storms was 56.7 inches, and the mean annual runoff measured at the watershed outlet was 5.7 inches per year. Data from a standard climatological station near the center of the watershed is also transmitted through the telemetry system. This information complements climatological data available from the U.S. Weather station at Batesville, MS. The scope and quality of data being collected at the Goodwin Creek Watershed has recently attracted the attention of scientists from NASA and NOAA working on large scale hydrometeorology and its relation to GEWEX Continental-Scale International Project. GEWEX stands for Global Energy and Water Cycle Experiment, and it is a World Climate Research Program (WMO) initiative to study the water and energy budgets of an extensive geographical area of the Earth with a large volume of accessible data. These components of the watershed database are described in Chapter 3.

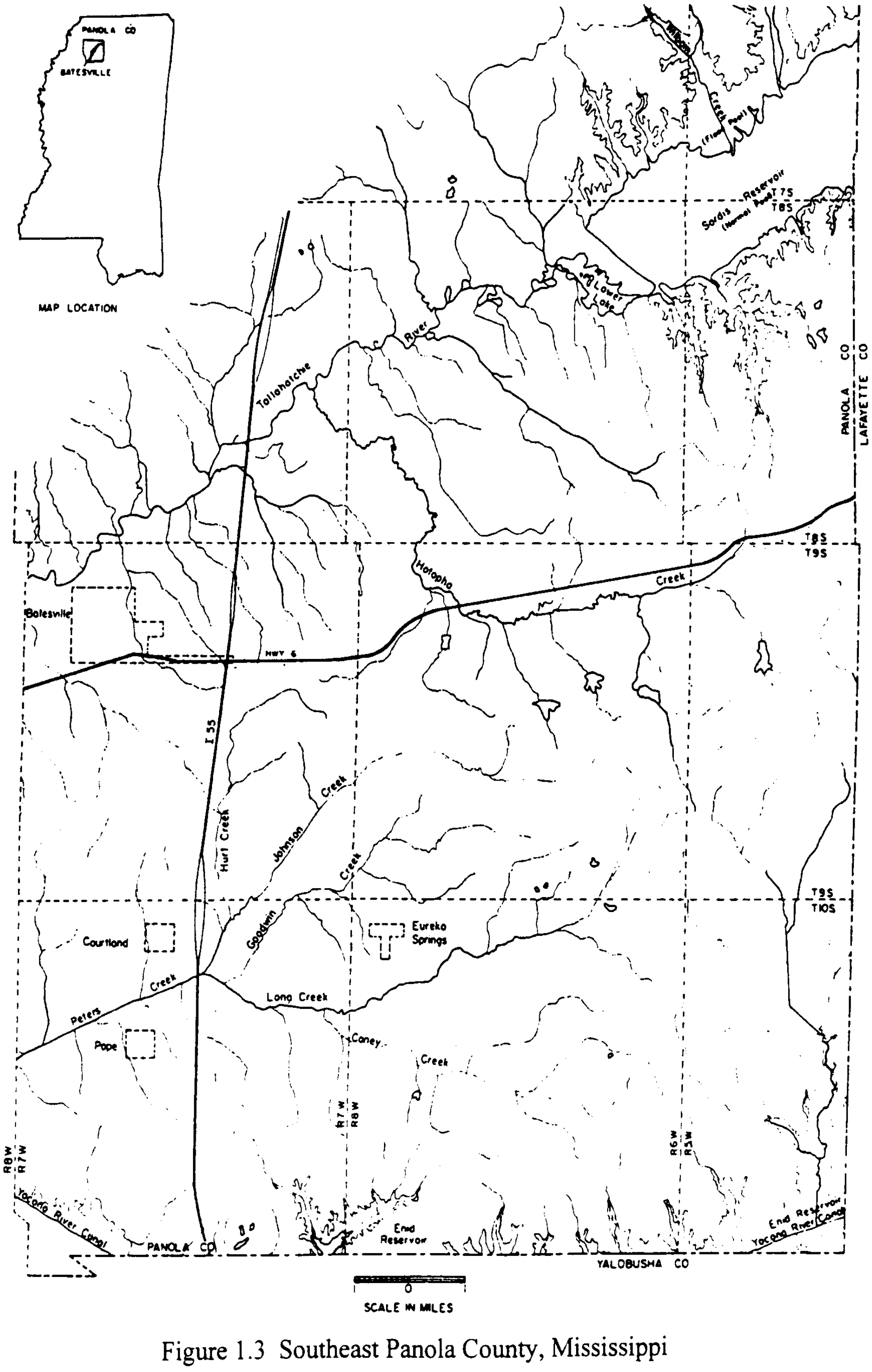


Figure 1.3 Southeast Panola County, Mississippi

The watershed flows approximately from northeast to southwest, it drains a total area of 8.26 square miles, with the outlet at latitude 89° 54' 50" and longitude 34° 13' 55". Terrain elevation ranges from 233 feet to 420 feet above mean sea level, with an average channel slope of 0.004 in Goodwin Creek. Land use and management practices that influence the rate and amount of sediment delivered to streams from the uplands range from timbered areas to row crops. The Goodwin Creek watershed is largely free of land management activities with 13 percent of its total area being under cultivation and the rest in idle, pasture and forest land. Periodic acquisition of aerial photography and satellite data contribute to complete aerial coverage of land use and surface conditions. All landscape and topographical features of the watershed are presented Chapter 4.

Measurements collected at each site and transmitted through the telemetry system include water stage, accounting of automatically pumped sediment samples, air and water temperature, and precipitation. Manual sampling of total sediment loads is also carried out during storm events at stations 1 and 2 using bedload and depth-integrating suspended sediment samplers. Surveys of channel geometry, bed material, bank geotechnical properties, and channel migration were conducted at periodic intervals to keep track of channel morphological changes. These measurements are described in Chapters 5 and 6.

A Geographic Information System is used to incorporate this and other spatially distributed data in a relational database. The complete database compiled since the inception of the project is available in CD-ROM format. The structure of the database is described in Appendix E.

Chapter 2

WATERSHED OPERATIONS

2.1 Background

The design of the data acquisition network for Goodwin Creek was dictated to a large extent by the nature of the hydrologic research to be conducted on the watershed. This research need was a part of the overall criteria guiding the reconnaissance for the selection of the watershed (see Chapter 1). In addition, other design criteria that were dictated by the specific research objectives of the project are described below. They included:

(1) A reach at the lower end should be available for routing studies. This reach should have no major tributaries entering the Goodwin Creek. The channel should be well defined and should by itself be an important source of sediment production. Also, the reach should be bounded at each end by stream gaging stations equipped to measure continuously stream flow (as stage), water temperature and, to the extent possible, total sediment discharge.

(2) The drainage area above the reach should be subdivisible by stream flow measuring stations into subbasins which are relatively homogeneous or which isolate significant sediment source areas or channels of differing stability. The homogeneity should cover land use, soils and geology as much as possible. The differences between the subbasins should be significantly greater than the differences within the subbasins. The areas isolated should reflect the major land uses in the subbasin.

(3) Where stream gages are in tandem or the subbasins are nested, the subdivision should isolate major tributaries and leave less than half of the intervening area ungaged.

(4) The location of the streamgaging stations should have reasonable access for construction and maintenance.

(5) The watershed should have a minimum of urbanized area.

(6) The location of stream gaging sites were to coincide with grade control structures to take advantage of the opportunity to use the structures as flow measuring devices.

2.2 Design of Nested Data Acquisition Network

The subdivision of the Goodwin Creek Watershed that resulted from the above criteria is illustrated in Figure 2.1. The Watershed was divided into fourteen subbasins with drainage areas ranging from 0.06 to 21.4 sq. km. Figure 2.1 shows the location of the nested gaging stations that were installed to monitor streamflows. The nested configuration was selected to ensure that in the main stem at least 60 percent of the total inflow is measured by other structures upstream.

The channel reach between stations 1 and 2 was selected as a testing site for streamflow routing. The reach has little major inflow and is a significant sediment source area. Station 1 was located about as far downstream as feasible without resulting in the lower reach becoming affected by backwater from the confluence with Long Creek. Station 2 was located just downstream from a road which gave convenient access. Upstream of the road, the channel changed in character to a more stable regime.

Stations 3 and 4 were established upstream of station 2. These upstream stations isolated the two major tributaries above station 2. Stations 13 and 14 split off two smaller tributaries above station 2. However, the primary reason for adding 13 and 14 was the character of the channel bed material above these stations, which consists primarily of gravel.

The drainage area above stations 3 and 4 were further subdivided by three additional stations located along a paved road crossing the watershed. These are stations 5, 6 and 7 which are readily accessible from the paved road.

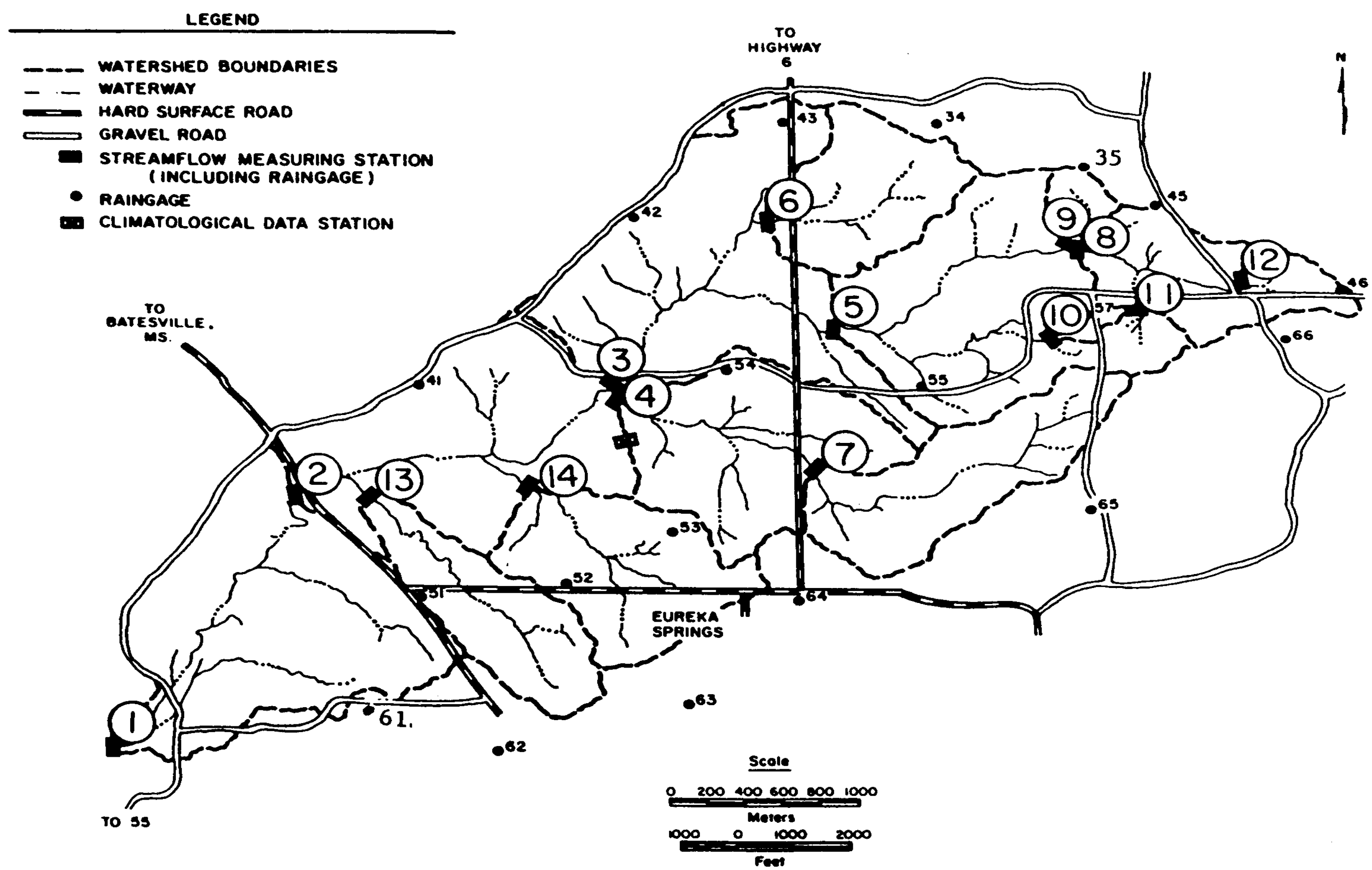


Figure 2.1 Goodwin Creek Experimental Watershed, Panola County, Mississippi

Above station 5 two other stream gaging sites were added resulting in stations 8 and 9. Station 9 isolates an area that was formerly cultivated and is extensively gullied. It is a major contributor of sediment and represents a significant area that is in similar condition. Station 8 was located at the same point on the main channel as a convenient point to subdivide the area above station 5. In this location, the same road and data collection station could serve both 8 and 9.

Station 10 was established on a small area that was completely forested. The area serves as a unit-source area for wooded land use. Station 11 was established at a site which consists almost entirely of pasture or idle land. Station 12 splits off the very upper end of the watershed. Below station 12, the channel changes dramatically in size and depth.

The measurements conducted to characterize the watershed hydrology include, but are not limited to, variables which directly affect the rate and volume of runoff, rate and amount of sediment production, delivery and particle size distribution, rainfall, stream temperature, land use, tillage practices, soil type, topography of the land surface, and soil moisture. Measurements implemented to define the watershed micro-climate encompass wind speed and direction, and air temperature. Additional weather parameters that were not implemented as part of the original design, include solar radiation, relative humidity and barometric pressure. These missing parameters are now being collected at the NOAA's SURFRAD station installed in the watershed in January of 1995 (see Section 2.4.3).

2.3 Stream Gaging Stations and Field Instrumentation

Streamflow and sediment loads reaching a stream reach represent net runoff and erosion from the upstream areas. In Goodwin Creek, flow events are highly variable, and sediment loads are usually transported during the most intense runoff events. It is not unusual for only two or three extreme events may contribute half the annual load of sediment from the watershed. Sediment movement in the stream system takes a long time to react to varying flows, sparodic bank failures, and man-induced pertubations. To reliably quantify the transport relationships for temporal variability and infrequent events, a long time period of observations is required. As the sediment is conveyed downstream it fill streams and reservoirs over long period of times. Therefore, the design and type of instrumentation, and data acquisition systems necessary to effectively monitor watershed processes must operate continuously over long periods of time and be capable of capturing short term events as well. These needs were considered in the design of the data collection system for the Goodwin Creek Watershed. Data on precipitation, water stage in the measuring flumes, accounting of automatically pumped sediment samples, stream water temperature, etc. are automatically collected at each gaging site and transmitted to the Laboratory via a radio telemetry system. All instruments, transducers, and telemetry equipment are contained in small instrument houses located adjacent to the flumes. This data acquisition system is explained in more detail by the following sections.

2.3.1 Flume Structures

A supercritical measuring flume was constructed at each subbasin outlet. All the flumes were designed and constructed to serve dual purposes, that is, they control degradation of the channel bed in the highly erosive streams and serve as flow measuring devices. The flumes were designed to operate in the supercritical flow range to ensure flushing of the high sediment loads carried by the channels. The construction of all flumes consists of reinforced concrete supported on sheet piling except site 10 where sheet metal was used. Construction of the flumes began in April, 1978, with flume 10. In September of 1978, flumes 2, 3 and 4 were constructed and later completed in December,1978. Structures 5, 6, 7, 8, 9, 11, 12, 13 and 14 started in June, 1979, and completed in October, 1979. Flume 1 was started in July of 1979 and completed in September, 1979.

The design parameters and locations for each of the 14 supercritical flumes are given in Table 2.1 along with the estimated 100-year recurrence interval peak discharge. The flumes at the smaller gaging sites (4-9 and 11-14) are "V" shaped with side slopes of 1-on-2 (Figure 2.2a and 2.2b). The larger flumes located at gaging sites 1, 2 and 3 are "U" shaped and have a floor with side slopes of 1-on-5 and walls with side slopes of 1-on-2 (Figure 2.3a and 2.3b). The floor section included in the larger flumes permits the structure to fit into the channel while still providing the desired hydraulic characteristics. In order to assure passage of all sediment entering the measuring section, the flumes were designed with a longitudinal slope of 4 percent.

In routing streamflow through the flumes, it is necessary to know the longitudinal thalweg profile. Hence, Table 2.1 gives the elevation of the flume bottom at the invert and at both the inlet and outlet sections. Additional information on stream cross-sectional geometry and thalweg elevations both upstream and downstream of the flumes is given in Chapter 4. Appendix A contains plan views of each site showing the alignment of the channel reaches immediately upstream and downstream of the flumes.

2.3.2 Water Discharge Measurements

The instantaneous rate of water discharge past each stream gaging station during a runoff event are computed from rating relationships that give the rate of water discharge, Q, as a function of the water stage, H, measured at the flume invert and a point immediately downstream of the flume outlet. The rating relations are all expressed in the power form:

$$Q = mH^{n}$$

where Q is in ft^3/sec, and H is in feet. The coefficient and exponents in this relationship vary with stage level and from station to station. Hence, they were experimentally determined during the initial calibration of the supercritical flumes. Table 2.2 gives the values of *m* and *n* for each station and stage range. The stage is measured at each station using a redundant system that involves the use of both conventional chart recorders and electronic transducers linked to the telemetry system. The recorders are used with standard time-stage charts which provide a hard copy back-up in the event of failure of some component of the telemetry system during storm runoff.

At each station, a conventional FW-1 chart recorder is used for recording the water level at a point in the flume where the flow goes through supercritical stage. The recorders were modified by

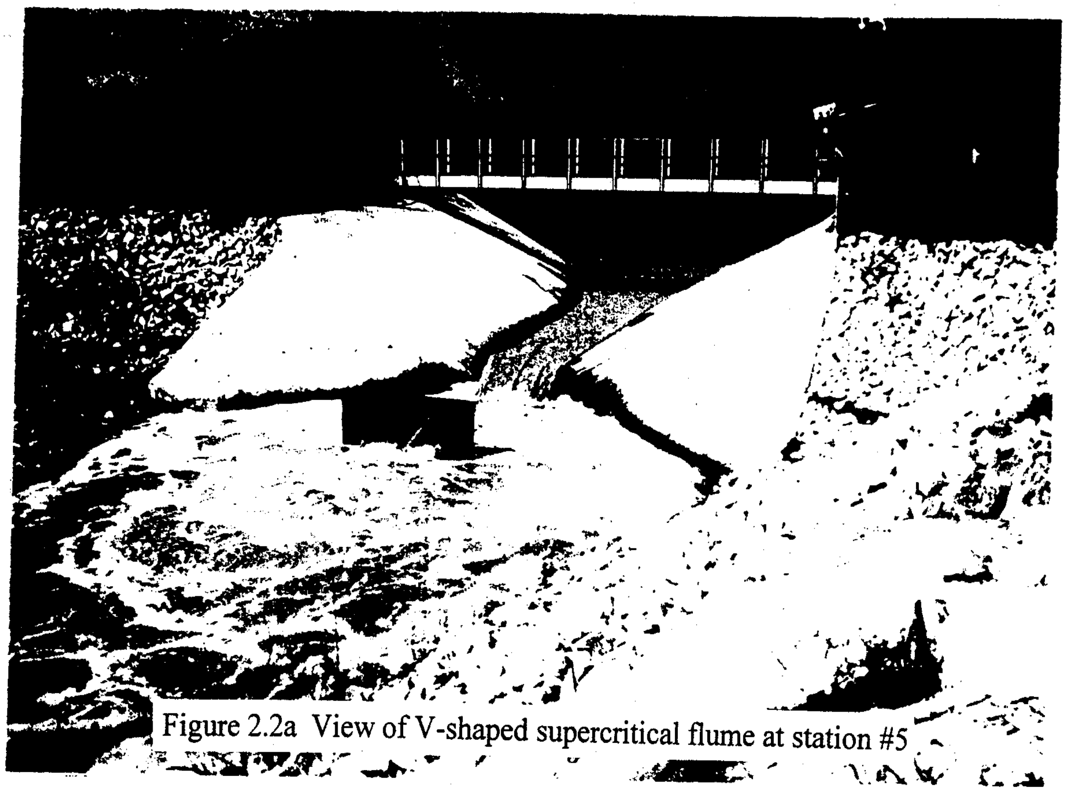


Figure 2.2a View of V-shaped supercritical flume at station #5

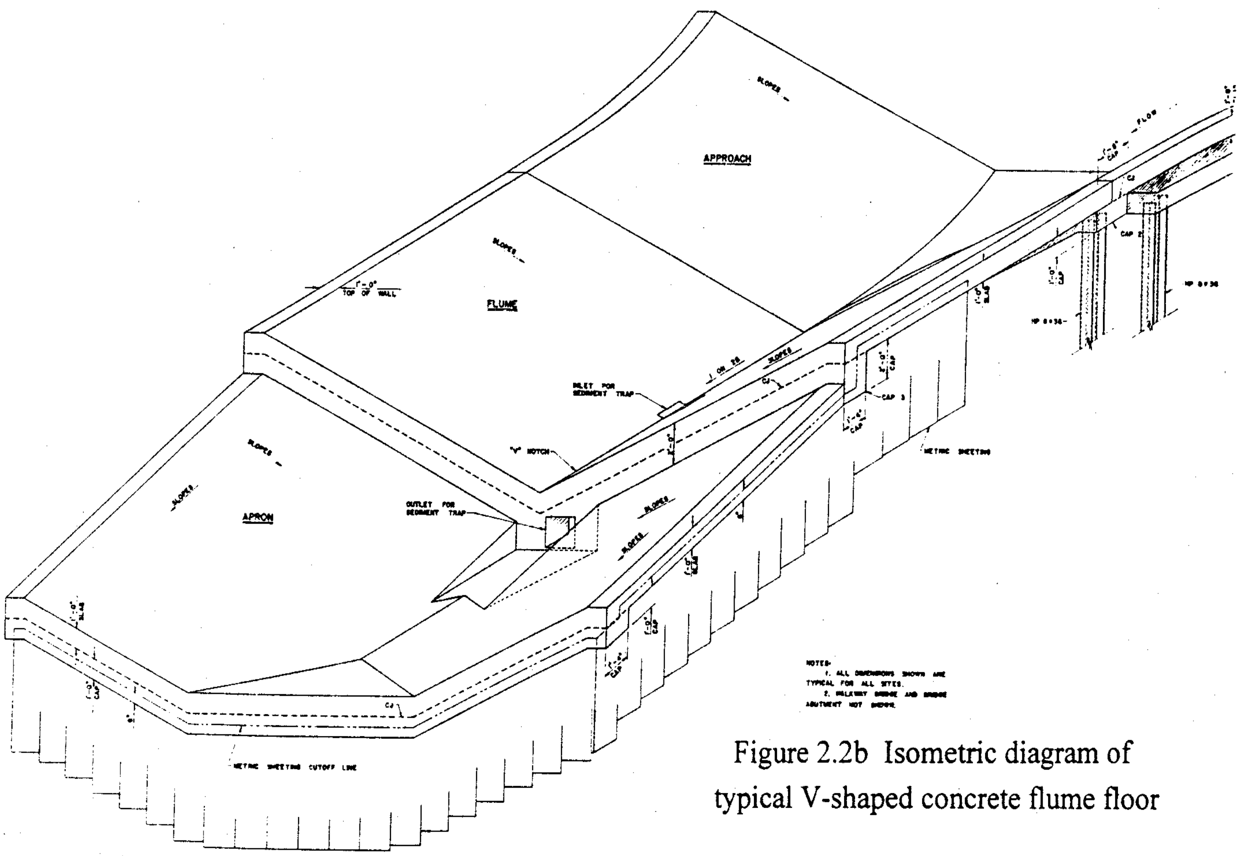


Figure 2.2b Isometric diagram of typical V-shaped concrete flume floor

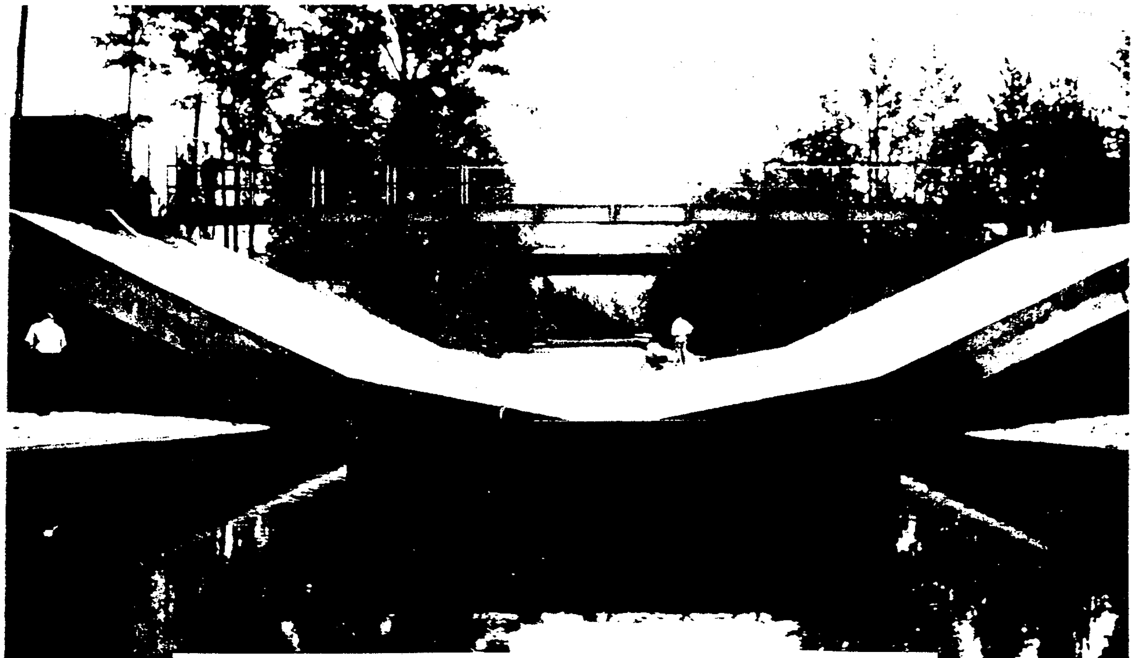


Figure 2.3a View of U-shaped supercritical flume at station #2

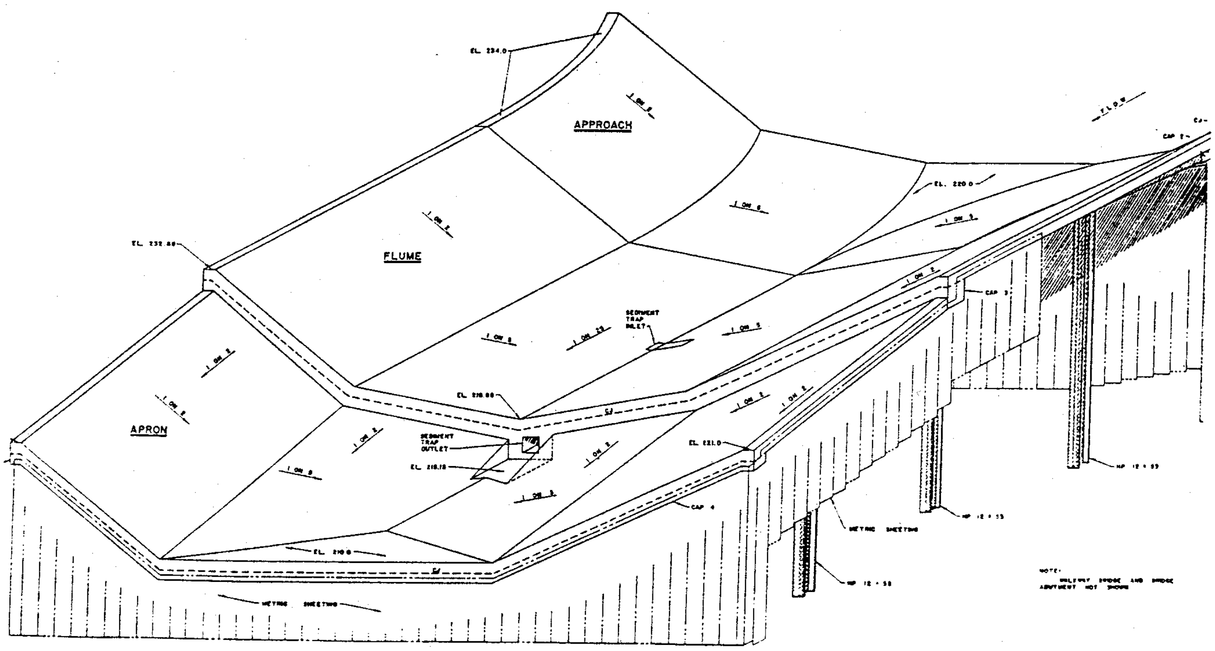


Figure 2.3b Isometric diagram of typical U-shaped compound-slope concrete flume floor

Table 2.1 Design Parameters and Locations of Supercritical Flumes in Goodwin Creek Watershed

Gaging Site No.	Drainage Area (Km)	100 yr Discharge (cms)	Depth at Measuring Sectio n (m)	Total Depth of Flume (m)	Bottom Width (m)	Distance to Meas. Section (m)	Flume Length (m)	Upstream Elevation (m)	Invert Elevation (m)	Downstream Elevation (m)	Location Lat / Lon (D,M,S)
1	21.39	176	3.08	4.27	9.14(1/5)	4.27	8.53	67.06	66.71	66.14	34 13 56.063 89 54 51.000
2	17.92	156	2.90	3.96	9.14(1/5)	4.27	8.53	74.22	73.88	73.46	34 15 03.937 89 53 54.564
3	8.78	91	2.21	3.20	9.14(1/5)	4.27	8.53	81.53	81.19	80.47	34 15 32.471 89 52 29.293
4	3.57	45	2.30	3.20	V*	3.66	7.32	82.30	82.00	81.38	34 15 27.986 89 52 25.712
5	4.30	57	2.53	3.66	V	3.66	7.32	89.76	89.47	88.85	34 15 47.473 89 51 28.178
6	1.19	17	1.55	3.20	V	2.44	4.88	89.76	89.57	89.15	34 16 16.082 89 51 44.665
7	1.60	31	2.01	2.90	V	2.44	4.88	90.68	90.48	90.22	34 15 10.342 89 51 34.479
8	1.55	28	1.93	3.05	V	2.44	4.88	99.67	99.47	98.91	34 16 09.930 89 50 21.643
9	0.18	13	1.38	2.59	V	2.44	4.88	100.28	100.08	99.21	34 16 10.878 89 50 21.920
10	0.06	3	0.79	0.91	0.61(1/5)	1.83	2.44	Not Available	Not Available	Not Available	34 15 45.461 89 50 27.910
11	0.28	10	1.24	2.44	V	2.44	4.88	106.53	106.33	105.77	34 15 54.106 89 50 03.844
12	0.30	11	1.31	2.29	V	2.44	4.88	110.79	110.60	110.03	34 16 00.231 89 49 35.254
13	1.24	23	1.76	1.98	V	2.44	4.88	80.77	77.83	77.42	34 15 03.271 89 53 35.741
14	1.63	24	1.52	1.98	V	2.44	4.88	81.36	81.19	80.47	34 15 07.040 89 52 53.252

* V indicates the entire flume is V - shaped

using a direct drive coupling to a potentiometer using excitation voltage provided by the analog interface card and calibrated for 1 volt change to equal 1.0 ft (0.305 m) stage rise. This system provides data with approximately 1/1000 of 1 inch (1/400 of 1 centimeter) accuracy. The transducer output is the signal sampled by the telemetry system. Data points are taken at one minute intervals with the system being sensitive to all stage changes in channel flow.

From their inception, stations 2, 7, and 13 experienced high tailwater levels that cause their calibration to deviate from the theoretical curves at high stages. Unfortunately, these are the stages and flows for which the most accurate measurements are needed. A characteristic of the supercritical flume design is that the Froude number decreases with increasing stage and this leads

Table 2.2 Flow Rating Table for Flume Structures

Station Number	H range, in feet		m	n
	From	To less than		
1, 2, 3	0.000	0.180	58.699	2.583
	0.180	0.328	45.243	2.431
	0.328	4.108	38.948	2.297
	4.108	bankfull	57.183	2.025
4, 5	0.000	0.310	18.403	2.492
	0.310	bankfull	14.882	2.310
6,7,8,9,1 1,12,13	0.000	0.322	15.557	2.423
	0.322	2.375	13.613	2.305
	2.375	bankfull	13.109	2.348
10	0.000	0.084	65.581	2.619
	0.084	0.234	40.991	2.429
	0.234	0.298	25.450	2.101
	0.298	bankfull	17.7756	1.804
14	0.000	0.269	24.658	2.443
	0.269	bankfull	20.775	2.313

to portions of the flow at the end of the structure being subcritical at high tailwater levels. An empirical adjustment to the rating curves for these stations was implemented that has apparently fixed the problem. At least in the case of station 2 this correction seems to give reliable discharge measurements in relation to flows through stations 3 and 1.

2.4 Sediment Sampling Instrumentation

2.4.1 Background

Measurements of the sediment loads are important parts of the Goodwin Creek data collection program. Unfortunately, when it comes down to sampling total sediment loads in streams, automation possibilities are still limited by the state of the technology. For this reason, the sediment sampling program in Goodwin Creek was designed to utilize conventional methods that involve the intervention of field operators.

In the early days of the program, primary emphasis was placed on the automatic pumping samplers for measurement of the sand and finer fractions of the sediment load. Density cells were placed in the sample lines and interfaced with the telementry system in attempt to obtain nearly real-time records of sediment concentration. However, this approach was plagued by problems caused by a low sensitivity that precluded their utility for the concentrations typical of those for flood flows in Goodwin Creek, suction causing small air bubbles to come out of solution, and frequent plugging of the U-tube of the density cells. About the same time, the computerization of the NSL sediment analysis laboratory was completed enabling bar-coding of physical samples and computer control of the analysis procedure. This system worked so well that the decision was made to discontinue the density cells and replace them by standard pumping sumplers at all sediment pumping stations. The fine sediment loads (<62 microns) can be measured by almost any means that provides a total water/sediment sample. This is indeed confirmed by the Goodwin Creek experience where the agreement between the concentrations of fine sediment in the manual and automatic samples is good.

Although some sand is collected by the pumping samplers, the validity of the sand concentrations from a single point in the supercritical structures proved to not be a reliable indicator of the sand in transport. Manual measurements at the outfall of the flumes using a DH-48 intake is still considered our "best" measurement of the sand load. Initial plans were to install sampling booms at each of the stations of Goodwin Creek and to have staff available for storm duty so that all stations could be manned during a storm event. However, this plan did not materialize to its full extent and manual measurements are only obtained at stations 1 and 2, and occasionally at station 3. Emphasis is being placed on these stations to try to determine the effects of the recently installed bank protection on the bed material load.

Gravel loads are being measured by two means - bedload box samplers at stations 2, 13, and 14, and a Helley-Smith sampler mounted on the boom at station 2. Unfortunately, the box samplers operate only until they are filled and this is only for a few minutes of major flow events; they are used mostly for specialized studies. The Helley-Smith samples are time consuming but give a more extended measure of the transport rates, although their use is limited to the short time windows of flow events.

In summary, sediment loads are systematically measured using a pumping sampler, equal-transit-rate samplers, and a Helley-Smith sampler. These sampling methods are used to measure the transport rates of the fine (<0.062 mm), sand (0.062 - 2.0 mm), and gravel (>2.0 mm) sized sediments, respectively.

2.4.2 Point Sediment Samples

The concentration of the fines from point samples has been found to be representative of the cross section mean value. The best coverage of the different stations and for most of the storms has been obtained for the fines using the automatic pumping samplers. The two types of pumping samplers used in Goodwin Creek are the USGS PS-69 sampler and the ARS Chickasha sampler. The PS-69 sampler has a good back-flush system and a capacity of 72 samples, but its operation is limited to 25 feet of suction head. It shows high pump failure when sampling heavy sand concentration. The PS-69 samplers are used only at sites where these limitations are not a factor. At sites where the sample intakes are long distances from the pump and where heavy sand concentrations are involved, the Chickasha samplers are used. These samplers are modified to use a different pump that can handle the heavy sand concentrations and pump continuously under adverse conditions. Also, they are fitted with an air-operated double-diaphragm pump that will self-prime up to 100 feet of head, easily controlled by air pressure, simple to maintain and can pump particles up to 3 millimeters in diameter.

2.4.3 Equal-Transit-Rate Samples

Motorized booms mounted on a footbridge were installed at some of the largest stations to aid in the sampling of total sediment loads. A standard USGS DH-48 sediment sampler is attached to the traversing arm of the boom that drives the sampler at a constant speed. Due to a well known limitation in the design of the DH-48 sampler, the lowest 6 inches of the flow depth of a stream is left unsampled. To eliminate this unmeasured zone the DH-48 intake nozzle is positioned just downstream of the flume outlet, thus enabling sampling over the entire depth of flow. During a storm event the booms are manually positioned at regular intervals across the flow width to obtain an integrated measure of the total sediment load.

2.4.4 Bedload Sampler

A modified Helley-Smith (MHS) type sampler is used for collecting bed load samples. The intake orifice of the sampler has been modified from a square 7.62 cm on a side, to a parallelogram with the same area. The sloping bottom surface of the MHS sampler allows it to rest firmly on the sloping surfaces of the supercritical flow flumes where the samplers are used. The exit area of the sampler is the same as the original sampler. Hydraulic efficiency of the MHS sampler has been shown in a laboratory study to be nearly the same as for the original sampler. The MHS sampler is used from a sampling rig similar to the one used with the DH-48 sampler but positioned on the upstream side of the footbridge.

2.4.5 Box Samplers

Two continuously-recording box samplers are used to measure bedload transport rates at stations 13 and 14. The rate of sediment accumulation into each box is accomplished by measuring the pressure due to the submerged weight of the sediment on a pressure pillow beneath the box. A differential pressure transducer, with one side connected to the pressure pillow and the other side to a USGS bubble gauge, gives a voltage that is proportional to the dry weight of the sediment in the box. The bubble gauge discharges into the outer box to compensate for the pressure on the pillow due to the depth of water in the channel. Another pressure transducer connected to the bubble gauge provides a voltage proportional to the depth of water over the box. The samplers were calibrated by placing weighed amounts of sediment into the inner boxes and recording the voltage change of the pressure transducer. A linear relation between dry sediment weight and voltage change was obtained. A diagram of the box sampling setup is shown in Figure 2.4.

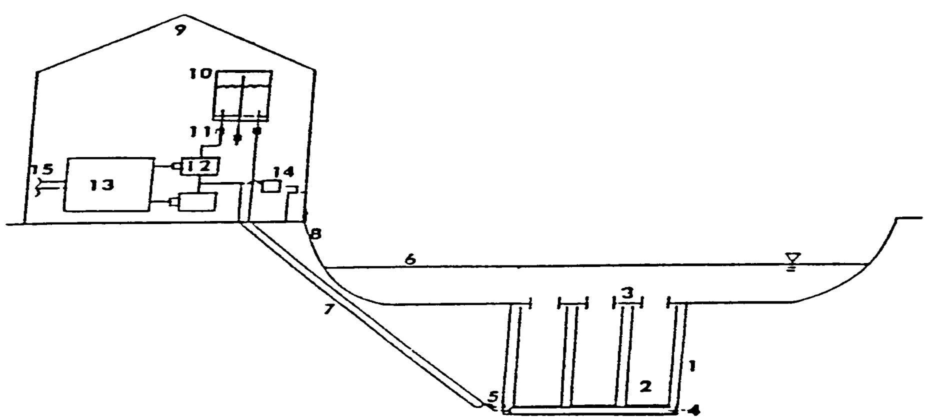


Figure 2.4 Schematic cross-sectional view of Box-Sampler installation. Numbers on diagram represent: (1) outer box, (2) box compartment, (3) slotted cover, (4) pressure pillow, (5) bubble tube inlet, (6) water surface, (7) tubes from bubbler and pillow, (8) stream bank, (9) instrument house, (10) air trap, (11) valves, (12) pressure transducer, (13) power supply, (14) bubble gauge, (15) wires to remote telemetry system.

Elevation of the water surface is also measured 100 feet upstream from the box-samplers using a bubble gauge and pressure transducer. The upstream and box bubble gauges allow the slope of the water surface to be calculated and thus obtain a continuous record of the driving tractive forces. During operation, the pressure transducers are sampled at one minute intervals and stored for 30 minute intervals in the mini-computer located at the station site. The data is then downloaded every 30 minutes via the telemetry system.

2.5 Climatological Data

A standard climatological station (station 50, Figure 2.1), located near the center of the watershed, was initially setup to collect weather data such as precipitation, wind speed and direction, air temperature, etc. However, this station was never brought fully on line because of operational problems. As a result, the nearest source of climatological data for the entire period of record is the station maintained by the National Weather Service at the nearby town of Batesville.

In 1995, a cooperative agreement with the National Oceanographic and Atmospheric Administration (NOAA) resulted in the installation of a SURFRAD station (see Section 2.7). In addition to solar radiation instruments, this station includes instruments for barometric pressure, relative humidity, and in time it will be converted into a complete climatological station.

2.5.1 Precipitation Gages

Spatial distribution of rainfall on the Goodwin Creek watershed is continuously monitored with a network of 32 standard recording weighing precipitation gages located at sites both inside and outside the watershed area (Figure 2.1). The coordinates of gage locations were measured and calculated using a Global Positioning System (WGS-84, Clarke 1866). The latitude and longitude (in degrees, minutes and seconds) that define the position of each gage are shown in Table 2.3.

The raingages are equipped with transducers consisting of special purpose potentiometer coupled to each gage. Each gage is capable of 1/400 of 1 centimeter accuracy. The transducers output voltage is recorded on standard digital dataloggers. However, due to cost, these stations were never connected to the remote telemetry system. Although field technicians regularly monitor and

Table 2.3. Precipitation Gage Locations

Gage Number	Latitude	Longitude
1	34 13 56.063	89 54 51.000
2	34 15 03.937	89 53 54.564
4	34 15 27.986	89 52 25.712
5	34 15 47.473	89 51 28.178
6	34 16 16.082	89 51 44.665
7	34 15 10.342	89 51 34.479
8	34 16 09.930	89 50 21.643
10	34 15 45.461	89 50 27.910
11	34 15 54.106	89 50 03.844
12	34 16 00.231	89 49 35.254
13	34 15 03.271	89 53 35.741
14	34 15 07.040	89 52 53.252
34	34 16 41.410	89 50 53.987
35	34 16 28.684	89 50 14.093
41	34 15 30.417	89 53 28.670
42	34 16 20.945	89 52 17.623
43	34 16 43.439	89 51 37.734
45	34 16 21.076	89 49 53.542
46	34 15 57.845	89 49 12.503
51	34 14 34.077	89 53 20.858
52	34 14 38.784	89 52 44.621
53	34 14 50.465	89 52 09.013
54	34 15 37.226	89 51 58.946
55	34 15 32.223	89 50 52.756
57	34 15 34.599	89 50 14.562
61	34 14 05.003	89 53 50.592
62	34 13 59.425	89 53 02.068
63	34 14 18.295	89 52 07.695
64	34 14 37.827	89 51 38.822
65	34 15 00.044	89 50 15.956
66	34 15 39.795	89 49 21.317

maintain the gages to ensure proper data collection and workability, some difficulty in maintaining calibration of the raingages has been experienced. As a back-up, each raingage is equipped with a standard depth recording chart in case of power failure during storms.

2.5.2 Air and Stream Temperature

Temperature probes are installed at the 14 stream gaging sites for accumulation of stream temperature data. The outside air temperature is recorded at gaging sites #2, #3, #12 and station #50. Air and water temperatures are measured with thermistor temperature sensors driven by transducers that relate the ambient temperature to the resistance of the probes. The transducers output voltage is downloaded via the telemetry system. The ambient operating temperature range for these sensors is -23 to +50 degrees Celsius, and the probe-transducer combined accuracy is better than or equal to ✂0.3 degrees Celsius.

2.6 Data Acquisition System

2.6.1 Remote Telemetry System

The remote telemetry system is a computer-based data acquisition system designed to collect and transmit electronic data from remote unmanned sites. The system consists of 14 microcomputer controlled, real time data collection systems linked to radio transmitters, a VHF radio repeater, and a central computer for data accumulation and processing.

The data is collected from the field sensors at individually selected sample rates of 1 to 15 minutes and stored in the microcomputer memory for later transfer to the central computer located at the National Sedimentation Laboratory in Oxford, Mississippi. Using automatic scheduling from the central computer, each station is polled a minimum of once over a thirty minute interval. After a station is polled, the station responds with a user programmed station identification and check sum followed by the installed sensors data list. The time of transfer between the station and the central computer at the laboratory is in minutes and hundredths of minutes. After receiving a complete message, the data is logged on the central computer disk for later data reduction and transfer to magnetic storage devices. If errors occur or are detected, the station is polled again to complete the data transmission. However, if errors are not recoverable, the data files are flagged as containing errors and the erroneous message is logged for later manual interpretation.

2.6.2 Transient Protection Devices

Transient protection devices are used in the Goodwin Creek Watershed to protect the field instrumentation and data accumulation system during the typically severe thunderstorms that commonly occur in the area. Transient voltages can destroy a common digital and analog system. The primary objective of transient protection is to prevent component failure and to provide revival capability of affected equipment.

Transzorb fast reacting power zener diodes were installed on all signal lines entering the field stations. This would be sufficient transient protection on most installations. However, the watershed is located in an area of severe thunderstorm activity and further protection is required. This is especially true where sensors are located well above the ground line. The installation of gas-discharge tubes directly at the sensor cable interface on above ground sensors was found to be a very effective device for eliminating large transients. Additional grounding procedures were also required for the radio transmitter system. A ground plane 4.6 meters in diameter was constructed approximately 1.0 meter below the ground surface and attached to a 1.8 meter long ground rod driven in the ground at the base of the antenna tower. A ground wire was attached to the top of the antenna tower and extended down one leg of the tower to the ground rod. The use of this technique has greatly reduced the interference of lightning with data transmission.

2.7 Earth Surface Radiation Measurements

2.7.1 Background

The Earth Surface Radiation Budget Network (SURFRAD) was established in 1993 by NOAA's Air Resources Laboratory through the support of NOAA's Office of Global Programs. Its primary objective is to support global change and related research with continuous surface radiation measurements. Long term ground-based observations from SURFRAD are useful for evaluating satellite-based estimates of the surface radiation budget and estimates of solar irradiance at the surface. These data are also valuable for validating hydrologic, weather, and climate prediction models, and to detect trends in the earth's climate, either occurring naturally, or forced by continuing changes in atmospheric concentrations of radiatively active "greenhouse" gasses.

A cooperative research agreement was formalized between the USDA National Sedimentation Laboratory, Oxford, Mississippi, and the Air Resources Laboratory of NOAA's Surface Radiation Research Branch (SRRB), Boulder, Colorado, on October 24, 1994, to install and operate a SURFRAD station at the Goodwin Creek Experimental Watershed. This station is part of the SURFRAD network planned by NOAA.

2.7.2 The SURFRAD Network

When complete, the network will be made up of seven stations distributed over the continental United States. The site selection process for SURFRAD was a collaborative effort among NOAA, NASA, and university scientists. Locations were chosen with the intent of best representing the diverse climates of the United States. In choosing specific locations, special consideration was given to places where the landform and vegetation are homogeneous over an extended region so that the point measurements would be qualitatively representative of a large area. These properties are especially desirable to those who will use SURFRAD data to validate models that infer surface radiation properties from satellite data.

The three established stations were installed in 1994 within the Mississippi drainage Basin in support of the Global Energy and Water Cycle Experiment's (GEWEX) Continental-Scale International Project (GCIP). They are the Goodwin Creek Watershed, Fort Peck in northeastern Montana, and Bondville in east central Illinois. A third station is planned at Boulder, Colorado, that will also serve as a calibration facility for network instruments, as well as for spectroradiometers operated by several U.S. agencies that monitor ultraviolet (UV) radiation. The three other sites have yet to be determined although most probably two will be located in the forested regions of the northeast and northwest, and another in the desert southwest United States (Figure 2.5).

All of the established stations have local hosts and are located within well-monitored drainage basins to support hydrologic research. The station in northwestern Mississippi is located in the Goodwin Creek Experimental Watershed. It is hosted and attended by the USDA National Sedimentation Laboratory, which is located adjacent to the campus of the University of Mississippi.

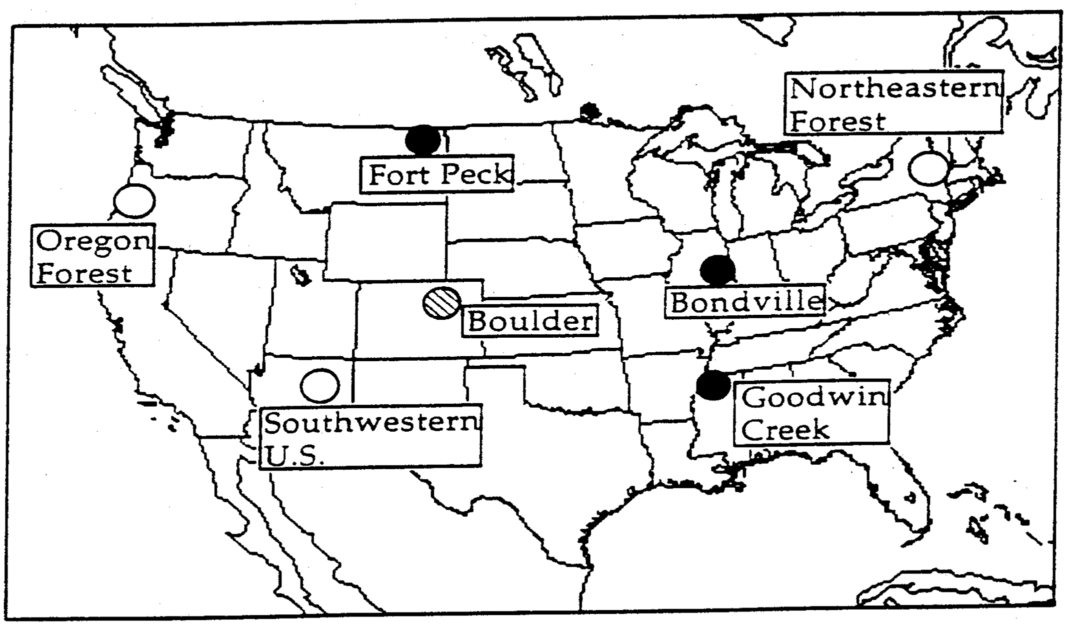


Figure 2.5 Location of Current and Prospective SURFRAD Stations (black are established, shaded are desired, white are prospective)

The station in northeastern Montana is located on tribal lands of the Fort Peck Tribes, and is attended by the Fort Peck Tribes, which has been actively involved in environmental monitoring for more than a decade. Bondville is in a flat agricultural region and is co-located with several other experiments on a site managed by the Illinois State Water Survey. The station at Boulder will be attended by the Surface Radiation Research Branch (SRRB) of NOAA's Air Resources Laboratory, which is the managing agency for SURFRAD.

2.7.3 SURFRAD Instrumentation Strategy

The three platforms that house the instruments and support equipment are aligned north-south. The upward-viewing radiometers rest on a long rectangular platform (~1 ft. by 8 ft.) which is made of an off-white grating. It is elevated about 4 to 5 ft. off of the ground by two 4 in. diameter steel posts set in concrete. The data logging, power distribution, and communication equipment are fastened to these posts. A separate post about 10 ft. south of the main platform supports an automatic sun tracker. About 50 ft. due north of the main platform is a 10-m tower with downward viewing radiometers and meteorological instruments mounted near the top. The tower is north of the other platforms, and the crossarm that supports the downward looking radiometers is aligned north-south. This orientation ensures that the tower, and the instruments mounted on it, will never shade the upward-viewing radiometers on the platform. Electrical power for the instruments and support equipment is conditioned by a 1.15 KVA uninterruptable power supply unit that has the capability to supply power through battery backup for a short period (~2 hours) if the line power fails.

Radiation measurements at SURFRAD stations cover the range of the electro-magnetic spectrum that affects the earth/atmosphere system. Direct solar radiation is monitored with a normal incidence pyrheliometer mounted on the automatic sun tracker. Downwelling global solar radiation is measured by an upward-viewing broadband pyranometer. The diffuse component is not measured, but computed by subtracting the direct solar measurement from the global measurement. Because the direct measurement is made normal to the sun, it must be corrected to a horizontal surface (by multiplying by the cosine of the solar zenith angle) before this difference is computed. This method is reliable for solar zenith angles[1] less than about 75 degrees. However, when the sun is near the horizon, a change in the response of the pyranometer introduces errors in the global measurement which compromise the diffuse calculation. A second broadband pyranometer is mounted facing downward on a crossarm near the top of the 10-meter tower to monitor solar radiation reflected from the surface. An upward viewing pyrgeometer on the platform measures thermal infrared radiation emitted downward by clouds and other atmospheric constituents; and another pyrgeometer, also mounted facing downward on the crossarm atop the tower, senses upwelling thermal radiation from the surface. There are two instruments on the main platform that monitor wavebands of special interest. One is a UVB radiometer that measures the degree of harmful ultraviolet radiation (290-315 nm) that evades the ozone layer and reaches the surface. The other monitors the intensity of the waveband active in photosynthesis (400 to 700 nm). The last radiometer in the SURFRAD suite is the Multi-Filter Rotating Shadowband Radiometer (MFRSR) which measures both global and diffuse solar radiation in one broadband channel and six narrow bands of the solar spectrum. Ancillary instruments for measuring wind direction and speed, air temperature, and relative humidity are mounted at the top of the 10-meter tower. Additional details on these instruments are given in Appendix B.

Campbell Scientific Inc. data logging equipment is used to sample and record data from all instruments except the MFRSR, which has its own logger. The sampling rate for all instruments except the MFRSR is one second, and the logger has been programmed to record three-minute averages and standard deviations. The MFRSR spot samples at 15-second intervals and one-minute averages are recorded. Meteorological data are averaged and recorded for 15-minute and one-hour periods.

Future enhancements to SURFRAD stations depend on funding, but may include the addition of a shaded upward-viewing pyranometer, and the shading of the upward-viewing pyrgeometer. With the addition of a shaded pyranometer, the diffuse component would be measured directly. This would enhance quality control by providing the ability to compare measured and computed diffuse radiation;

[1] The solar zenith angle is defined as that from the local zenith to the sun.

and in addition, improve the accuracy of the global radiation measurements when the sun is near the horizon. Shading the upward-viewing pyrgeometer would reduce errors caused by the heating of its dome by the sun, and thus improve the accuracy of the downwelling thermal radiation calculation. A barometer will be added to the suite of meteorological instruments for a continuous record of air pressure at SURFRAD stations. The three stations in the Mississippi River drainage basin may be equipped with Global Positioning Satellite (GPS) receivers and associated hardware which would allow for the retrieval of total-column water above the sites. Finally, upward pointing lidars may be added to give accurate cloud base and cloud thickness measurements. These last three enhancements will provide information crucial to radiative transfer calculations.

2.7.4 Calibration of SURFRAD Instruments

SURFRAD has adopted the standards for measurement set by the Baseline Surface Radiation Network (BSRN) which is sponsored by the World Climate Research Program (WCRP) of the World Meteorological Organization (WMO). These are ±5 Watts/m^2 for broadband solar measurements and ±10 Watts/m2 for thermal infrared measurements. In an attempt to achieve these ambitious goals, the instruments are calibrated to absolute standards. The broadband solar instruments are calibrated at the National Renewable Energy Laboratory in Golden, Colorado against standards traceable to the World Radiation Center in Davos, Switzerland. Presently, because of the lack of an acceptable standard for infrared instruments, pyrgeometer calibrations are traceable only to standard instruments maintained by their manufacturer, Epply, in Newport, Rhode Island. However, results of the FIRE II experiment's BSRN-sponsored Infrared Radiometer Intercomparison at Coffeyville, Kansas, suggest that the Epply calibrations are actually acceptable to within approximately ±5 Watts/m^2. Calibrations of the spectral instruments such as the UVB radiometer and MFRSR will be carried out by SRRB's Calibration Facility which is presently under development. Standards used there will be traceable to the National Institute for Standards and Technology (NIST) in Gaithersburg, Maryland. Once the Calibration Facility is fully functional, it will have the capacity to check and recalibrate instruments in the field. SRRB plans to switch out the radiometers at each station at least once per year to check their calibrations. At the Calibration Facility's field site at Table Mountain near

Boulder, Colorado, SRRB maintains three reference instruments of each type that the SURFRAD instruments are checked against before and after deployment.

2.7.5 SURFRAD Data Distribution and Quality Control

The data processing, quality control, and distribution system for SURFRAD is under development. At present, the stations are polled automatically by modem once per day via a DOS computer station. The data are then transferred to a UNIX workstation and plotted for visual inspection. SRRB is now in the process of developing quality-control methods and a format for user-access data files. These data will soon be available via anonymous FTP. Based on input from experienced data base managers, it was decided that the files would be written in ASCII format, although they will likely be compressed. If so, the compression programs will also be made available. Since the MFRSR is still considered experimental, its data will probably not be included in the initial daily data set for general dissemination. SRRB also plans to make the ASCII data files and daily plots accessible from a home page on the World Wide Web.

Data from SURFRAD stations will be archived at several locations. Besides locally at SRRB, the data will be sent to the GCIP archive which is maintained by the University Corporation for Atmospheric Research (UCAR) in Boulder, Colorado. It will also be archived at ARL in Oak Ridge, Tennessee, and from there sent to NOAA's National Climatic Data Center in Asheville, North Carolina. Two international archives in Europe will also receive the data. It will first go to the BSRN archive in Zurich, Switzerland, which is maintained by the World Climate Research Program. From there it will be sent to the World Radiation Data Center in St. Petersburg, Russia.

Chapter 3

Climate

3.1 Climate of North Mississippi

Mississippi has a humid climate. The annual temperature for the state is approximately 65^0 F, ranging from an average of 62^0 in the northeast to 68^0 in the southwest. The annual precipitation ranges from about 50 inches in the northern part of the state to about 68 inches near the gulf coast in southeastern Mississippi. The principal source of moisture is the Gulf of Mexico from which tropical airmasses bring moisture inland from the gulf, particularly during summer and fall. Occasionally, moisture from the eastern Pacific Ocean reaches Mississippi. In general, precipitation is the result of convective showers from surface heating of moist air or the frontal lifting of moist air over polar continental airmasses moving into the state from the north. Precipitation resulting from frontal systems occur as general, widespread rain associated with warm fronts and as intense showers, squall lines, thunderstorms, and severe weather associated with rapid convergence of cold fronts with moist, tropical airmasses. Frontal systems are most common in late winter and spring (National Water Summary 1988-89) (Testa III and Lago,1994).

The climate of Goodwin Creek Watershed is humid, hot in the summer and mild in the winter. The area exhibits an annual temperature of approximately 63^0 F and a normal annual rainfall, as reported by the nearest official U.S. Weather Station, in Batesville, MS, of approximately 55 inches per year (1399 mm/year) (National Water Summary 1988-89)(Testa III and Lago,1994).

3.1.1 Air Temperature

A climatological station (station #50), located near the center of the watershed, is used to collect data such as precipitation, barometric pressure, relative humidity, wind speed and direction, and air temperature. Air temperature is collected and transmitted from gaging site #3 within the watershed using a thermistor air temperature sensor. The data is collected on a daily basis and is processed to determine a mean monthly average for each water year. In Table 3.1, the monthly and yearly distributions are given for the average daily temperature for the period of 1982 - 1993. Based on the monthly values, a temperature trend (Figure 3.1) shows the months of January and July to be the extremes in cold and hot, respectively (Seely *et al*,1981).

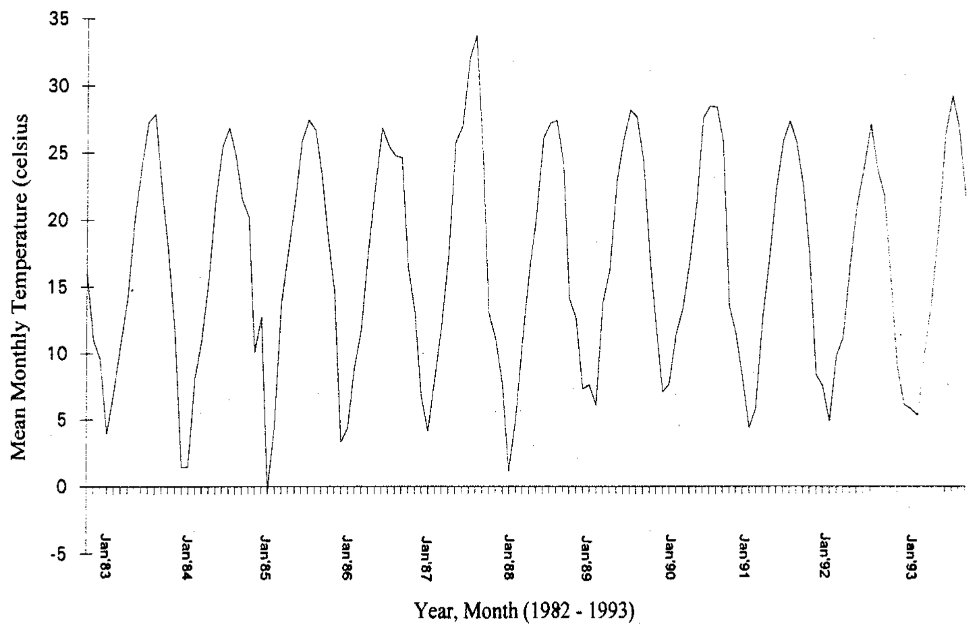


Figure 3.1 Monthly Air Temperature for Goodwin Creek

Table 3.1 Mean Monthly Air Temperatures for Goodwin Creek

(daily temperatures, recorded in degrees Celsius)

	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93
October	16.28	17.71	20.23	18.48	16.39*	13.06	14.13	17.28	13.53	17.33	15.83
November	11.01	11.75	10.09	14.64	13.08	11.10	12.63	12.18	11.58	8.40	9.03
December	9.60	1.46	12.72	3.30	6.79	7.68	7.31	7.08*	8.22	7.52	6.17
January	3.95	1.47	-0.33	4.42	4.11*	1.16	7.61	7.70	4.39	4.89	5.84
February	6.93	8.13	4.42	8.89	7.97	5.01	6.06	11.42	5.82	9.84	5.31
March	10.53	10.87	13.79	11.71	11.98	10.84	13.82	13.41	12.58	11.12	10.08
April	14.04	15.33	17.55	17.49	17.43	16.22	16.27*	16.80	17.25	16.59	13.98
May	19.90	21.62	21.44	22.46	25.78	20.19	22.95	21.19	22.36	21.03	19.57
June	23.96	25.43	25.87	26.82	26.99	26.09	25.95	27.58	25.90	23.89	26.43
July	27.25	26.82	27.42	25.54	32.03	27.20	28.13	28.48	27.36	27.13	29.22
August	27.86	24.81	26.66	24.76	33.71	27.38	27.65	28.39	25.74	23.81	26.91
September	22.17	21.49	23.36*	24.61	24.84	24.21	24.38	25.81	22.45	21.85	21.83

* Incomplete data, averaged mean value from period of record

3.1.2 Precipitation

The collection of precipitation data is important in the study of watersheds and their processes. To effectively evaluate rainfall and storm events, a network of precipitation gages was designed and installed in Goodwin Creek. The network consists of 32 gages which are spatially distributed throughout the watershed to provide the best coverage possible. The data collected by the gages is on a daily basis and presented by month for each water year (Table 3.2 and Figures 3.2, 3.3, 3.4 and 3.5). From Table 3.2, the data indicates that most of the rainfall occurs in the winter and spring, primarily in the form of rainfall, with very little snow or sleet. Additionally, a statistical summarization on a month-by-month basis for the period of record is given in Table 3.3 (Seely *et al*,1981).

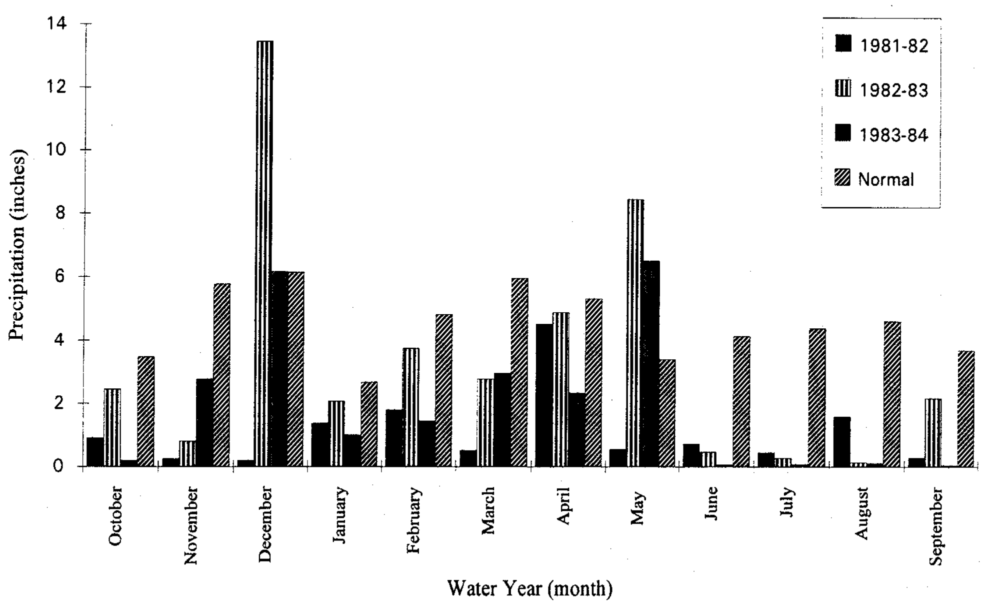


Figure 3.2 Goodwin Creek Precipitation, 1981-1984

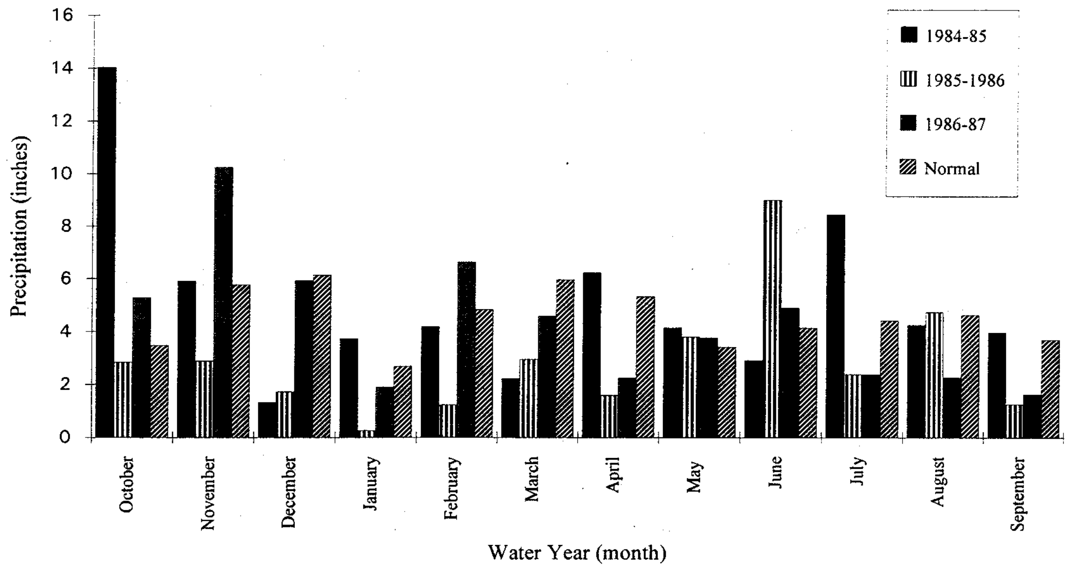


Figure 3.3 Goodwin Creek Precipitation, 1984-1987

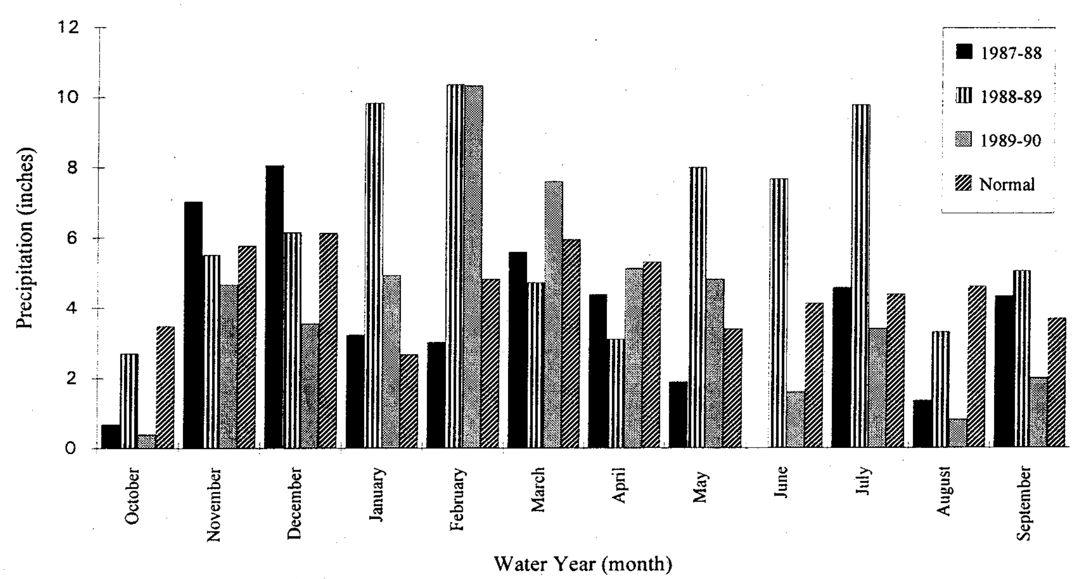


Figure 3.4 Goodwin Creek Precipitation, 1987-1990

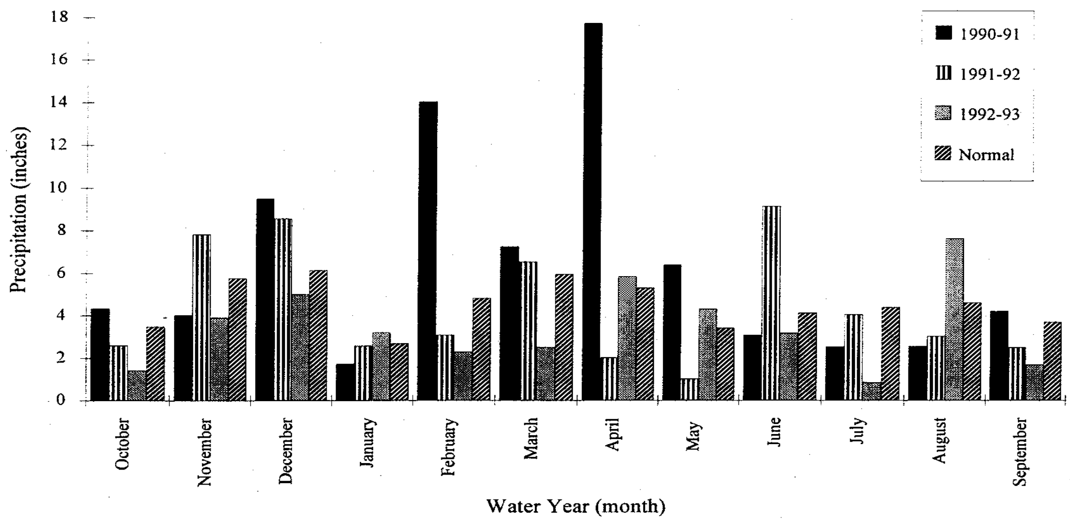


Figure 3.5 Goodwin Creek Precipitation, 1990-1993

3.2 Erosion

In the United States and around the world, soil loss is a serious problem. In the U.S., thousands of tons of sediment each year are lost to erosion of farm land. This loss of valuable land is considered to be a national problem. Congress has mandated research agencies, such as the Agriculture Research Service, to predict the amount of erosion that will occur and possible conservation practices to stop the process. Scientific planning for soil and water conservation requires knowledge of the relations between those factors that cause the loss of soil and water and those that help to reduce such losses. Controlled studies on field plots and small watersheds have supplied valuable information regarding these complex factor interrelations. The benefits from such research can be realized when the findings are converted to sound practice on the numerous farms and other erosion prone areas throughout the country. Specific guidelines are needed for selecting the control practices best suited to the particular needs of each site. The erosion model, Revised Universal Soil Loss Equation (RUSLE), provides guidelines for predicting and estimating soil loss. The model was mainly designed for agriculture purposes, but can be applied to areas where soil loss could be detrimental (Wischmeier,1978).

Table 3.2 Monthly Precipitation Data* for Goodwin Creek Watershed
Water Years 1982 - 1993 (precipitation in inches)

	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93	Normal
October	4.35	6.70	2.67	14.04	2.83	5.28	0.68	2.69	0.39	4.33	2.59	1.41	3.48
November	2.38	3.44	7.77	5.91	2.88	10.25	7.03	5.51	4.67	4.02	7.82	3.90	5.77
December	1.42	16.64	9.69	1.32	1.72	5.92	8.06	6.15	3.56	9.50	8.57	5.00	6.13
January	4.68	3.45	2.10	3.72	0.26	1.89	3.23	9.84	4.94	1.73	2.57	3.20	2.67
February	3.80	4.87	3.51	4.17	1.23	6.63	3.02	10.36	10.33	14.03	3.07	2.27	4.82
March	1.83	3.99	5.50	2.21	2.94	4.57	5.59	4.73	7.60	7.24	6.54	2.50	5.95
April	8.64	7.59	5.25	6.22	1.59	2.24	4.38	3.10	5.13	17.73	2.01	5.84	5.31
May	2.46	12.46	10.55	4.13	3.79	3.76	1.89	8.00	4.82	6.39	1.02	4.31	3.40
June	5.05	3.81	0.60	2.90	9.00	4.88	0.00	7.68	1.60	3.07	9.15	3.17	4.13
July	2.57	1.32	2.71	8.44	2.37	2.36	4.58	9.80	3.42	2.52	4.05	0.85	4.39
August	7.36	0.86	3.74	4.23	4.72	2.25	1.36	3.31	0.81	2.54	3.02	7.62	4.61
September	1.96	6.43	1.26	3.95	1.25	1.62	4.33	5.06	2.00	4.21	2.49	1.68	3.69
Total	46.50	71.56	55.35	61.24	34.58	51.65	44.15	76.23	49.27	77.31	52.90	41.75	50.87

- Monthly totals are Thiessen weighted and mean values

Table 3.3 Summary of Monthly and Annual Precipitation Water Years 1982 - 1993

Month	Maximum (inches)	Minimum (inches)	Mean (inches)	Standard Deviation (inches)	Coefficient of Variation	Percentage of Annual Rainfall
October	3.98	0.01	0.13	0.11	0.87	7.00
November	5.21	0.01	0.18	0.08	0.43	9.95
December	4.09	0.01	0.21	0.14	0.66	11.52
January	2.86	0.01	0.11	0.07	0.65	6.08
February	5.30	0.01	0.20	0.13	0.68	10.88
March	4.54	0.01	0.15	0.06	0.43	8.20
April	4.70	0.01	0.19	0.14	0.72	10.41
May	4.54	0.01	0.17	0.10	0.62	9.31
June	4.37	0.01	0.14	0.11	0.75	7.83
July	4.59	0.01	0.12	0.09	0.73	6.82
August	3.59	0.01	0.12	0.08	0.65	6.50
September	5.43	0.01	0.10	0.05	0.48	5.48
Annual	4.43	0.01	0.15	0.10	0.64	100.00

3.2.1 Properties and Types

Erosion is defined as the process by which materials of the earth, rock and soil, are worn away and removed by natural agents, such as wind, water, temperature change and biological. In addition to the natural agents, there are four factors which affect erosion, climate, soil, vegetation and topography.

(1) Climate is the refered to as the rainfall, temperature, wind, humidity and solar radiation.

(2) Soil is the physical properties effecting infiltration and the extent to which water is dispersed and transported.

(3) Vegetation is raindrop interception, retards runoff velocity, physical restraint to soil movement, improves aggradation and porosity of soil, decreases biological activity and transpiration.

(4) Topography is the degree of slope, length of slope, and the size and shape of the water channel.

To understand the processes involved with erosion, erosion is divided into different types or classes based on the depth of soil and flow. The four different types of erosion are sheet, rill, gully and stream bank.

(1) Sheet erosion is erosion in which the depth of soil is usually less than 1 inch; the erosion is dependent on the surface particle size.

(2) Rill erosion is when the depth of soil is less than 6 inches and can be obliterated by tilling the soil.

(3) Gully erosion is the result of concentrated flow between the downstream end of sheet and rill erosion and the upstream end of channel development. In general, gully erosion is considered an upland slope feature.

(4) Stream bank is erosion that occurs between the toe and top bank of a channel due to channelized flow such as a stream, creek or river.

3.3 Revised Universal Soil Loss Equation (RUSLE)

3.3.1 History

The development of a soil loss equation began in the Corn Belt region in 1940. The soil loss estimation procedure that developed between 1940 and 1956 was the slope-practice method, which related the rate of soil loss to the length and percentage of slope. The equation was revised in the following years to incorporate factors of crop practice, conservation practice, soil, management, and rainfall. In 1952, the formula came to be known as the Musgrave equation. From 1960 to 1965, the formula was improved and renamed the Universal Soil Loss Equation, USLE. Improvements included a rainfall erosion index, a soil erodibility factor, a method of evaluating cropping and management effects, and a method of accounting for effects of interactions between crop system, productivity level, tillage practices, and residue management. In the late 1970's, the USLE continued to evolve and was revised and renamed to RUSLE. RUSLE has taken each variable of the USLE and increased its' sensitivity for each factor (Wischmeier,1978).

3.3.2 Definition

RUSLE is an erosion model designed to predict the longtime average soil losses in runoff from specific field areas in specified cropping management systems. Its' purpose is to calculate the soil loss for a given area based upon specific parameters and conditions. The model is designed to determine erosion which occurs primarily from sheet and rill. The model is an expression of the equation **A = R K L S C P**, whose variables are defined as follows (Wischmeier,1978):

A is the computed soil loss per unit area, expressed in the units selected for K and for the period selected for R. In practice, these are usually so selected that they compute A in tons per acre per year, however, other units can be selected.

R is the rainfall and runoff factor; it is the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant.

K is the soil erodibility factor; it is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6 ft. length of uniform 9% slope continuously in clean-tilled fallow.

L is the slope-length factor; it is the ratio of soil loss from the slope length to that from a 72.6 ft. length under identical conditions.

S is the slope-steepness factor; it is the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions.

C is the cover and management factor; it is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P is the support practice factor; it is the ratio of soil loss with a support practice such as contouring, stripcropping or terracing to that with straight-row farming up and down the slope.

3.3.3 Erosivity Index

The rainfall and runoff factor, R, is a numerical value which quantifies the raindrop impact effect and provides information on the amount and rate of runoff associated with rain. To express the factor numerically, a rainfall erosion index was derived. The rainfall erosion index is determined to be directly proportional to a parameter identified as EI. EI is an abbreviation for energy-times-intensity, where energy is the total storm energy measured in hundreds of foot-tons per acre and I is the maximum 30 minute intensity measured in inches per hour. Through research, the EI parameter exhibits a linear relationship with soil loss and its' individual storm values are directly additive. The sum of the storm EI values for a given period is a numerical measure of the erosive potential of the rainfall within that period. The average annual total of the storm EI values in a particular locality is the rainfall erosion index for that locality. The EI values have been derived and applied to the United States (Figure 3.6) and, in turn, Mississippi (Figure 3.7).

In a study conducted by McGregor *et al* (1995), erosivity index values for northern Mississippi were computed and compared to nationally observed values using results from 16 years for Lab Creek, 19 years for Pigeon Roost Creek and 11 years for Goodwin Creek Watersheds. The research computed the annual rainfall erosivity (R) values during 1982 - 1992 for each watershed which included data from 29 of the standard recording rain gages in the Goodwin Creek Watershed using four procedures: Brown-Foster (RUSLE), McGregor-Mutchler, Agriculture Handbook 282, and

Agriculture Handbook 537. The computations were made to determine the adequacy of previously recommended erosivity values for northern Mississippi. The computed R values were found to be substantially higher than interpolated values given by RUSLE or in the Agriculture Handbooks 282 and 537. Results (Table 3.4) from the comparison show an interpolated value from the iso-erodent map (Figure 3.7) used in RUSLE to be 5790 MJ mm/(ha h) while the value obtained using the Brown-Foster equation to be 7968 MJ mm/(ha h). Conclusions from the study are that the erosivity values are too low for northern Mississippi (Goodwin Creek) and should be increased by approximately 30 percent (Mcgregor et al,1995).

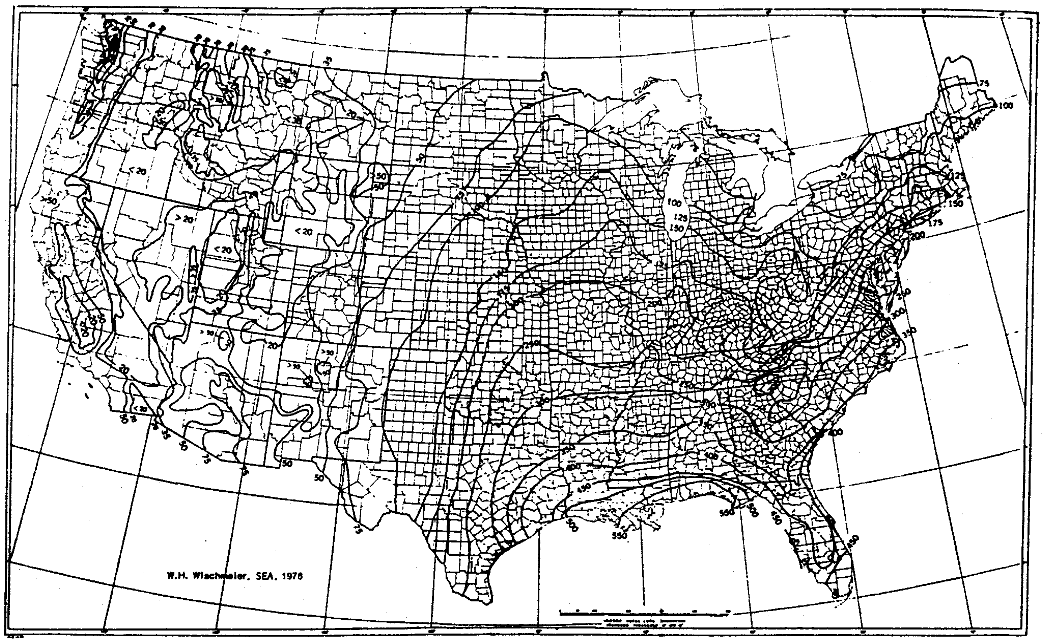


Figure 3.6 Average annual values of the rainfall erosion index for the United States.

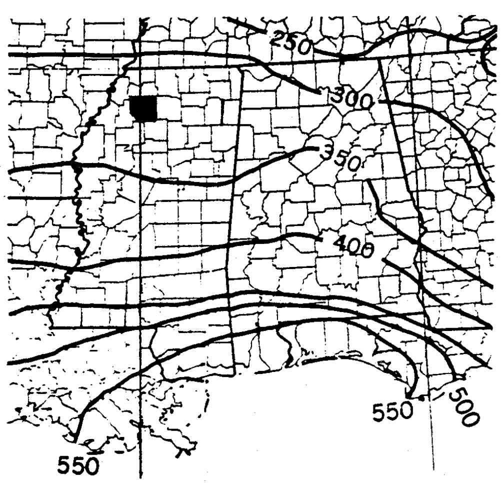


Figure 3.7 Average annual values for the rainfall erosion index for Goodwin Creek Watershed, Panola County, MS.

Table 3.4 Average Annual Rainfall for Goodwin Creek Watershed

Rainfall From All Storms						
Year	Number of Storms	Average (mm)	Standard Deviation	Maximum (mm)	Minimum (mm)	Median (mm)
1982	89	1699	63	1811	1568	1688
1983	74	1669	58	1775	1523	1676
1984	77	1448	40	1512	1361	1446
1985	76	1210	46	1319	1160	1196
1986	63	1234	38	1314	1133	1235
1987	70	1153	47	1237	1059	1155
1988	70	1055	30	1131	997	1056
1989	87	1792	47	1912	1725	1789
1990	86	1497	52	1662	1422	1494
1991	85	1999	60	2137	1884	1998
1992	76	1123	34	1188	1055	1120
Average	78	1444	-----	-----	-----	-----

Chapter 4

Watershed Characteristics

4.1 Geologic Setting

Goodwin Creek Watershed is located in the southeast quarter of Panola County, in northern Mississippi. This area is within the Coastal Plain Physiographic Province, with the western two-thirds in the Bluff Hills Subprovince and the eastern one-third in the North Central Hills Subprovince. The Bluff Hills Subprovince is a loess-covered area of relatively high relief immediately east of the flat Mississippi Alluvial Plain, while the North Central Hills is an area of moderate relief. Loess caps all interfluves but thins rapidly from west to east and Holocene alluvial deposits are present in all valleys. Drainage is westerly to the Mississippi River alluvial valley via the Yocona River for Goodwin Creek (Figure 4.1) (Grissinger and Murphey,1981) (Grissinger and Murphey,1983) (Grissinger and Bowie,1984).

4.2 Methods and Materials

In 1977, a study was initiated to evaluate both within-channel stability relations and watershed conditions that influence sediment and water delivery to the channels. As part of this study, investigations were made to determine the lithology (the character of the rock found in a geological area expressed in terms of its structure, mineral composition, color and texture) of near-surface units in four study watersheds in Panola County, Mississippi. To accomplish the task, eighty-five exploratory holes were drilled and logged in Hotophia, Johnson, Goodwin and Long Creek watersheds in Panola County (Figure 4.2). Of the eighty-five drill holes, most holes were cased to minimize sample contamination and relatively undisturbed cores were collected using either 1.5- or 3-inch diameter split spoons or 3-inch diameter Shelby tubes. Cemented materials were sampled using diamond core barrels. Most holes were sampled continuously but several of the deeper holes were skip-drilled. Maximum sampling depth was 211 feet and the ground surface elevations of test holes were established by surveying (Figure 4.2) (Grissinger and Murphey,1981) (Grissinger and Murphey,1983).

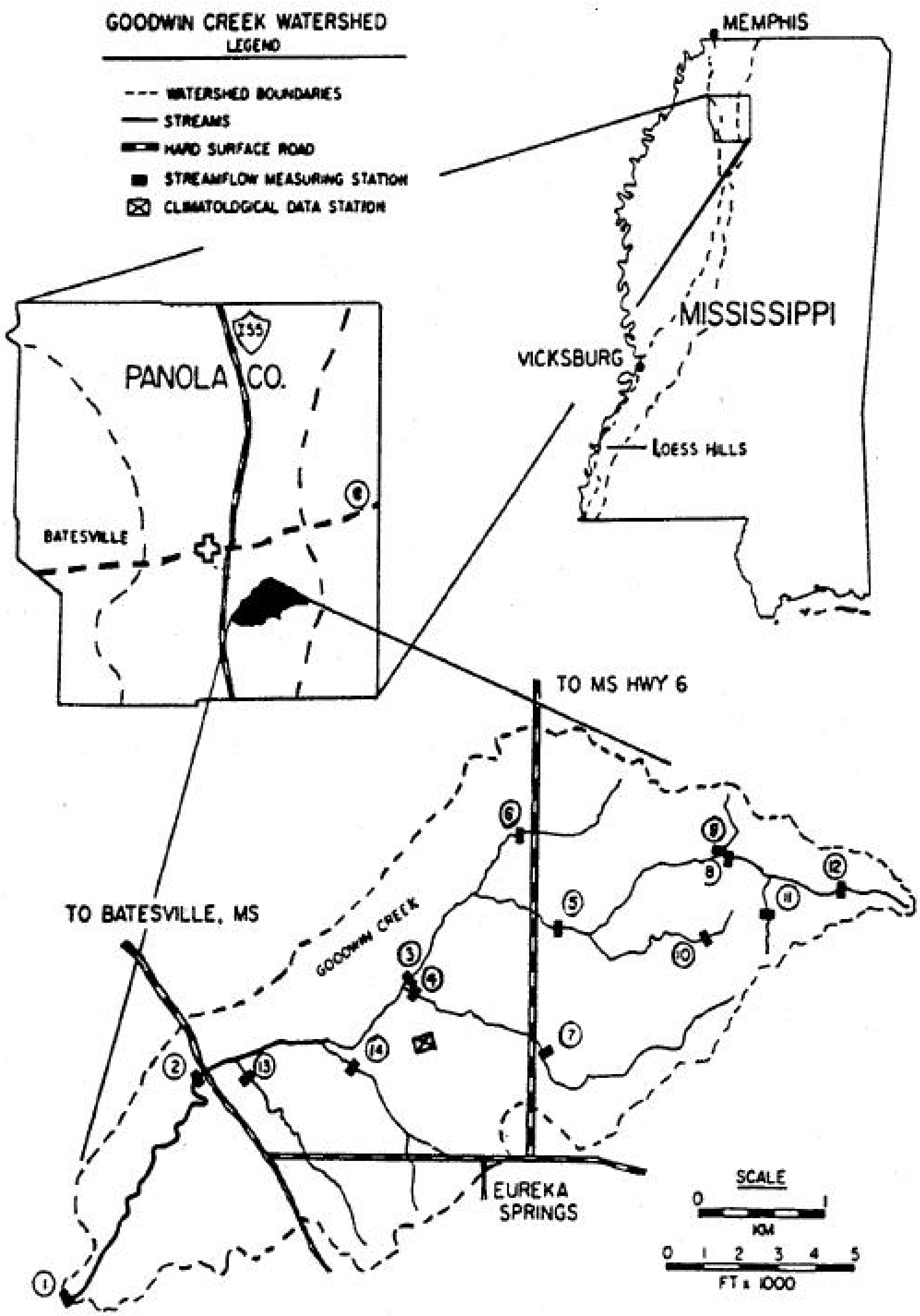


Figure 4.1 Goodwin Creek Experimental Watershed, Panola County, Mississippi.

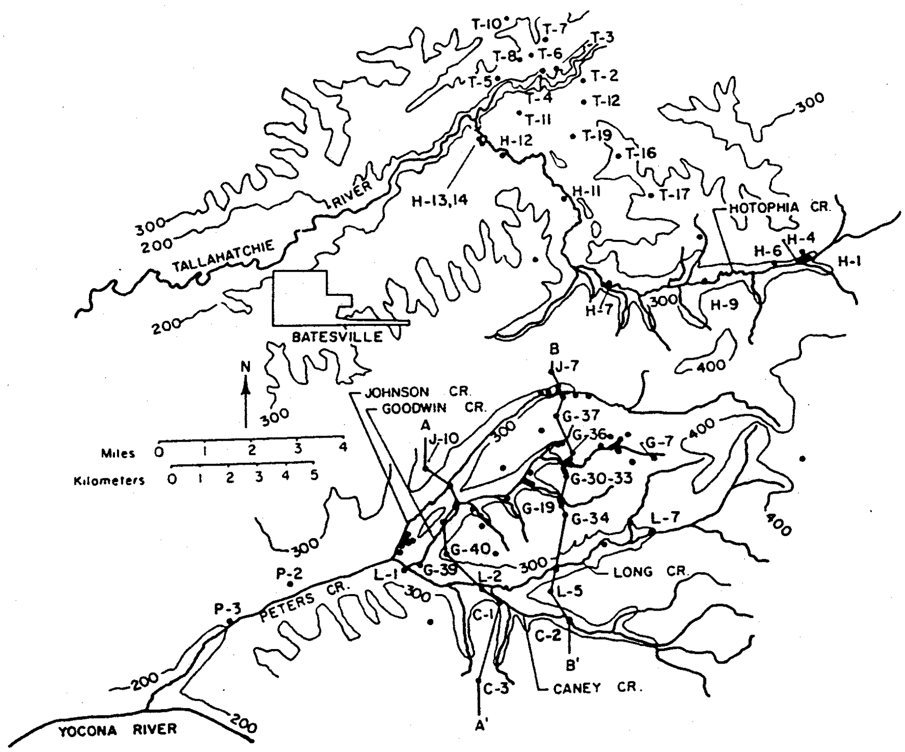


Figure 4.2 Location of exploratory holes in intensive study area, Panola County, MS.

A total of 6173 feet of material was drilled and several thousand samples were collected and described at the drill site. This field description included color, texture, depositional and weathering features, the nature of the contacts, and other distinguishing characteristics. Blow counts were recorded for half-foot incremental drives for split-spoon samples. Color was described using the Munsell system. In addition, chemical characterization was initiated for selected samples, including: pH, water soluble calcium, magnesium, sodium and potassium, and extractable hydrogen, aluminum and iron. Chemical analyses followed the procedures of the Soil Conservation Service (1972), presently the Natural Resources Conservation Service (NRCS) (Grissinger and Murphey,1981) (Grissinger and Murphey,1983).

4.3 Stratigraphy

The stratigraphy of the area is divided into formations (distinctive bodies of rock that serve as convenient units for study and mapping) of the Tertiary and Quaternary periods (systems). Five of these formations concerning the Goodwin Creek Watershed are -- the Citronelle, Kosciusko, Zilpha, Winona, and Tallahatta (Figures 4.3 and 4.4). Characteristic properties as reported by Vestal (1956) (Grissinger and Murphey,1981) (Grissinger and Murphey,1983) are:

<u>Citronelle formation</u> -- sand, sandstone, gravel and clay. The sand is coarse to fine, cross-bedded to the southeast, and cemented in places. Gravel is sparse and occurs as stringers to thin beds. Clay is present as lenses or is disseminated in the sand phase as a minor component.

<u>Kosciusko formation</u> -- sand, sandstone and reworked clay. Sand is fine to coarse and has variable colors ranging from light gray to chocolate or red-brown. Clays are pink, yellowish or white and occur as balls, nodules, stringers, or as matrix within the sands.

<u>Zilpha formation</u> -- clay, sandy silt, lignite, sandstone and siltstone. The fine sediments are shalelike, carbonaceous and brown to black when moist but dry to a gray color. They contain marcasite concretions and have a sulfide smell. They are layered and have laminae of micaceous silt to fine sand. The sands are fine, carbonaceous, gray to black,micaceous and also have a sulfide smell.

<u>Tallahatta formation</u> -- shale, clay sand, silt, sandstone and siltstone. The Neshoba member is composed of clean to argillaceous fine sand and is usually yellow to gray with some red to brown staining. Clay is present as matrix material, laminae, stringers or thin beds. This member is frequently micaceous and occasionally cemented. The Basic City member is shalelike to clayey, usually light colored but occasionally brown to red, micaceous, and has scattered thin seams of organic material. Outcrops of this member are frequently cemented.

The Winona formation was not positively identified or described by Vestal for Panola County. Priddy (1942) described it in Tallahatchie County as follows:

Winona formation -- Sand, silt, clay and claystone. This formation is slightly to very glauconitic, micaceous to very micaceous, carbonaceous, and has variable colors ranging from grayish-tan to greenish-brown to brownish-black. Clay is frequently present as thin stringers, laminae or beds. Outcrops oxidize rapidly to bright red to brown colors.

SYSTEM	**SERIES**	**FORMATION**	**MEMBER**
Quaternary	Holocene	Recent Alluvium	
	Pleistocene	Loess	
Tertiary	Pliocene	Citronelle	
	Eocene-Claiborne	Kosciusko	
		Zilpha	
		Winona	
		Tallahatta	Neshoba
			Basic City

Figure 4.3 Generalized Section of Stratigraphic Units, Panola County, MS (after Vestal, 1956). Dashed lines indicate discontinuity (or erosional contact) surfaces.

Based on research by Grissinger and Murphey, seven lithologic units have been identified in the Holocene valley-fill deposits. These units are (1) post-settlement alluvium, (2) meander-belt alluvium, (3) channel fill, (4) massive silt, (5) bog-type materials, (6) unconsolidated grey silt and (7) channel lag deposits. The units are divided into three depositional sequences from oldest to youngest of the Holocene, early, mid and late (Figure 4.4 and 4.5) (Grissinger and Murphey,1983).

The early Holocene depositional sequence contains two members. The younger (overlying) unit is the massive silt (4 above). The massive silt is fine-textured, dense and neutral to alkaline in pH (Table 4.1, Figure 4.5). The massive silt overlies any of the other three units (5, 6, & 7 above) in this sequence. Contacts vary from disconformable to fining-upward gradational interfaces. Organics are common in all units except the massive silt deposit, and Carbon 14 ages for these organics comprise the early Holocene frequency mode. The massive silt unit is a widespread, predominantly fine-textured valley-fill deposit. It is present in all valleys and frequently exceeds 4 m in thickness. Unit truncation or complete removal by erosion at some valley sites is common. Bedding is rare and has been observed only in the sandier zone of (gradational) contact with the subjacent member. The weathering profile on the massive silt termed, paleosol II, is distinctive. This paleosol has no A1 horizon, a thick A2 horizon and a dense B2 horizon with a well-developed, distinctive polygonal structure with vertical seams of weakly cohesive material, often 2 cm or more wide. These seams of unconsolidated material create planes of weakness which accentuate gravity-induced block failure. The polygonal seams are continuous from the top of the massive silt into the basal phase. A distinguishable basal phase of the massive silt is present. The phase has more clay than the superjacent (typical) massive silt and is usually separated from it by a sharp textural contact. This basal phase usually occurs as narrow ribbon-like deposits, suggesting that it may be fill in an abandoned stream course (Grissinger and Murphey,1983) (Grissinger and Bowie,1984) (Little *et al*,1982).

The older (underlying) member of the early Holocene sequence contains the unconsolidated gray silt, the bog-type material and the channel lag units. They are considered to be facies of one chronostratigraphic member of this sequence, separate from the massive silt member. The channel lag deposits are relatively coarse textured and the bog-type deposits are largely organic. Both are highly erodible. The gray silt unit is relatively stable due largely to its' relatively high bulk densities, moderately cohesive clay content, high moisture content, and lack of polygonal structure (Table 4.1) (Grissinger and Murphey,1983) (Grissinger and Bowie,1984). The member has an average age estimated (Grissinger *et al*,1982) to be 10,000 yr BP (years before present).

The mid-Holocene sequence consists of only the channel-fill lithologic unit which was deposited following a period of apparently rapid but areally-limited stream entrenchment. Sediments are relatively coarse textured with little or no cohesion, are gray to buff colored and have a poorly-defined weathering profile. Bedding ranges from lenticular to festoon cross-stratification but is often difficult to discern. These deposits are present in all valleys but are not widespread. The average age of these deposits is around 5,000 yr BP. In general, the material is highly erodible (Table 4.1, Figure 4.5) (Grissinger and Murphey,1983) (Grissinger and Bowie,1984).

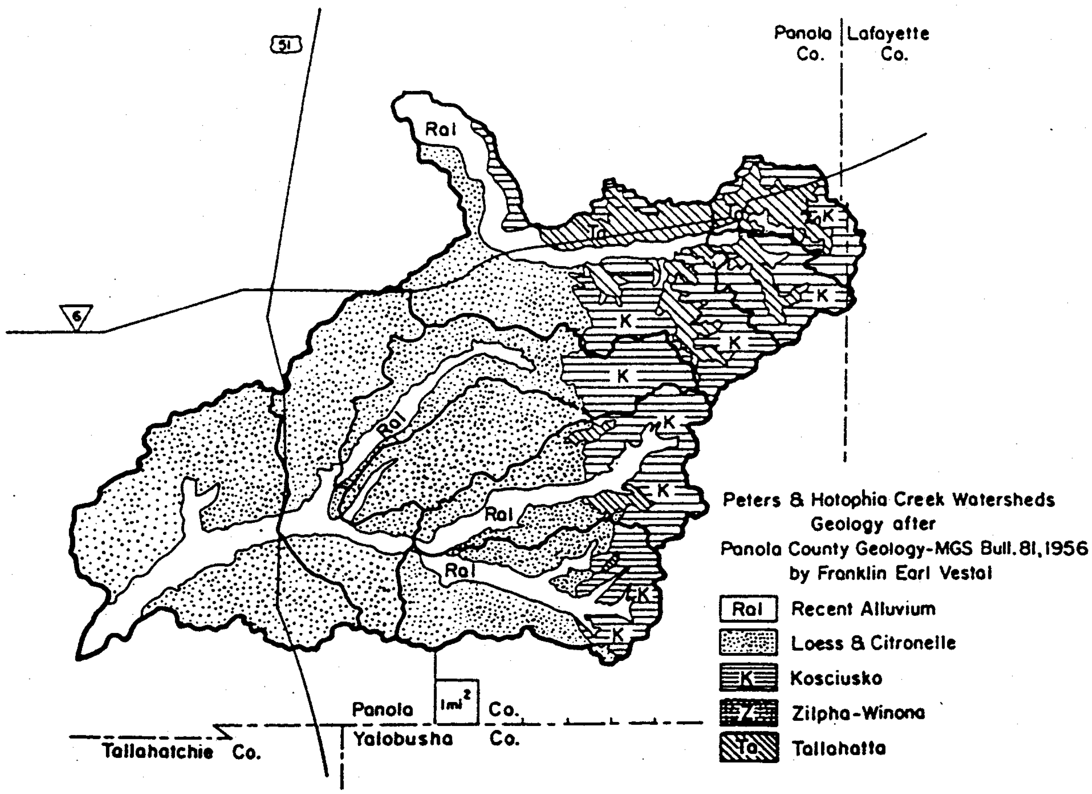


Figure 4.4 Geologic Map of Peters (Long) Creek and Hotophia Creek

The late Holocene sequence includes two lithologic units, the post-settlement alluvium (PSA) and meander-belt alluvium (MBA). The PSA and MBA units are the most recent valley-fill deposits and overlie all older units. The MBA deposits were laid down by the presettlement stream system. Channels not repositioned in their valleys would be located within the areal limits of a thick section of this deposit. The PSA sediments resulted from cultural activities during the late nineteenth and early twentieth centuries. They are the upper-most deposits and their main influence is that of loading underlying deposits (Table 4.1, Figure 4.5) (Grissinger and Murphey,1983) (Grissinger and Bowie,1984).

PSA sediments cap almost all flood plain surfaces. These deposits are the product of erosion of the loess-capped ridges and have formed in the past 130 to 150 years due to cultivation of the uplands. Thickness varies from less than 1 m up to 4 m, but is generally 1m to 1.5 m thick. The entire thickness of the material is highly permeable except for plow pans developed by agricultural practices. The PSA has well-preserved fluvial bedding ranging from horizontally discontinuous to lenticular to micro-cross stratification. It is unweathered, with an Ap horizon directly overlying a C horizon (Grissinger and Murphey,1983) (Little *et al*,1982).

MBA sediments include both vertical and lateral accretion deposits having a maximum age of about 3000 years before present. These sediments are distributed throughout the valleys, unconformably overlying older deposits. The entrenched streams apparently meandered across the flood plain, eroding older sediments and depositing the MBA sediments in a well-defined meander belt. The material is a fine silt to medium sand and is relatively unweathered. It has no polygonal structure, is relatively fertile and is well drained. The sand phase of the unit is very erodible and mass slab failures are common indicating very low strength. The unit has an A1 horizon which varies in thickness from a few centimeters to more than 25 cm, no A2 horizon and a weakly developed B horizon. The A1 horizon appears similar to these formed in prairie grass ecosystems. This weathering profile has been named paleosol I. Fluvial bedding is readily observable but is less well preserved than that in the PSA. (Grissinger and Murphey,1983) (Grissinger and Bowie,1984) (Little *et al*,1982). Although each of these units occur in the study area, the early Holocene massive silt and the late Holocene MBA units are the most abundant.

Table 4.1 Particle Size, Bulk Density and pH of Samples of Lithologic Units Identified in Figure 4.6

Lithologic Unit	Elevation (meters)	pH	Bulk Density (g/cc)	Particle Size*		
				Sand	Silt	Clay
PSA	73.6	5.02	1.51	20	72	8
	73.3	5.15	1.62	74	25	1
MBA	73.0	5.16	1.45	25	71	4
	72.5	5.39	1.59	11	80	9
	72.5	5.17	1.52±	15	78	7
Massive Silt	72.2	6.02	1.70±	3	84	13
	71.8	6.61	1.69±	1	82	17
	71.5	7.25	1.63±	1	79	20
	71.2	7.58	1.63±	3	79	18
	70.9	7.99	1.63±	2	81	17
	70.6	7.98	1.63±	2	83	15
	70.5	7.66	1.65±	2	87	11
	70.4	7.30	1.60±	3	85	12
Gray Silt	70.2	7.75	1.66±	3	88	9
	70.0	7.39	1.65	1	88	11
	69.8	7.03	1.62	2	89	9
	69.5	6.60	1.68	4	85	11
	69.4	6.55	1.63	4	89	7
	69.3	6.34	1.58	5	82	13
	69.1	6.55	1.54	3	89	8

PSA = postsettlement alluvium, MBA = meander-belt alluvium
*Particle diameter of sand is 0.062 to 2.0 mm; of silt 0.002 to 0.62 mm; and of clay, <0.002mm

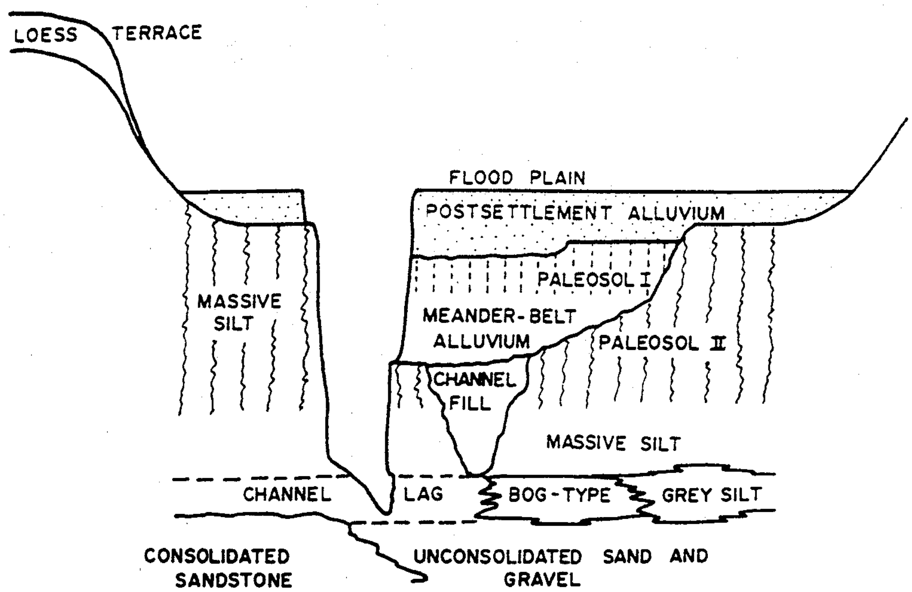


Figure 4.5 Idealized Section of Lithologic Units

4.4 Channel Morphology

In Goodwin Creek, the terrain of the watershed mainly consists of broad ridges and narrow valleys. As stated above, the ridges are capped with loess deposits, while the valleys are filled with alluvium derived from post-European settlement erosion overlying a complex of approximately six stratigraphic units, all of which are erodible. European settlement of the area, which began about 1830, was followed by deforestation, cultivation, rapid erosion of hillsides and accelerated valley sedimentation. Valley bottoms were covered by up to several meters of sediments eroded from hillslopes and swampy conditions developed due to impaired drainage. Landowners, acting as individuals and through drainage districts, attempted to reclaim valley lands by channelizing streams and constructing drainage ditches between about 1840 and 1930. Most of these efforts were poorly planned and ineffective. A second round of channelization and construction of major flood-control reservoirs on receiving streams by federal agencies occurred between about 1930 and 1960 (Shields,1994).

Due to the channel planform alterations by settlers, the positions of the streams in the valleys were often changed so that channels were steeper and were no longer within the late Holocene meander-belt deposit. In the 1990's and 1950's, large flood-control reservoirs were built on the major rivers above the point of confluence of many tributaries, Goodwin among them. As a result, Goodwin Creek responded to channelization and the reduction of flood stages on receiving streams by rapid incision. Incision often occurred by upstream progression of knick-points ('head-cutting') (a length of channel having a greater slope than that upstream or downstream). Presently, incision (entrenchment) is still in progress in many streams of the study area producing widespread problems of bank instability which are financial burdens to both private and public interests (Grissinger and Murphey,1983).

These two processes, of channel realignment and incision, have changed many of the streams from alluvial channel systems to systems presently controlled by the properties and distribution of the mid-Holocene and older valley deposits. The erosion-resistant lifetime of these units are significant to current channel behavior, especially to channel instability problems. The types of failure and the processes involved in bank and bed failures are controlled by properties of individual lithologic units and by unit sequences (Grissinger and Murphey,1983).

4.5 Channel Bed and Bank Stability

Bank materials which control stability include post-settlement and meander-belt alluvium, channel fill and the early Holocene massive silt, bog-type, channel lag and unconsolidated silt deposits. Failure of the post-settlement and meander-belt alluvium results from gravity stress, in many instances accentuated by tension crack development. The tension cracks are vertical and parallel with the banks. Failure of the massive silt also results from gravity stress with failure mass defined by the polygonal structure typical of the paleosol II - type weathering. The frequency of failure is related to current incision (entrenchment), which has increased bank height and steepness and has exposed the relatively weak bog-type and channel lag deposits in a bank toe position. These two units, when dewatered, are compressible leading to the tension crack formation. Materials of both deposits are easily eroded by channelized flow whereas the unconsolidated silt has sufficient cohesion to be relatively stable. Channel-fill materials are also easily eroded by channelized flow. Although failure is primarily gravity controlled, continuing instability is perpetuated by removal of the slough material by channelized flow and the rate of removal is controlled by disaggregation of the slough blocks (Grissinger and Murphey,1983). The mean soil strength parameters and the attendant mechanisms of bank failure for Goodwin Creek and the surrounding area have been researched and presented by Thorne *et al* (1981) and Little *et al* (1982) (Table 4.2).

Channels downstream of knickpoints have sand-to-gravel beds and the stability of these beds is primarily dependent on sediment supply to, and transport properties of, the hydraulic system. Three units affect the rate of knickpoint migration. The oldest unit, and one that does not crop-out on the surface in Goodwin Creek but does in adjacent catchments, is the Eocene Zilpha formation. Its shaley character often creates sills or cataracts that retard headcut migrations for decades. Outcrops of the pre-Holocene (Figure 4.2) consolidated sandstone also function as bed-control sills and inhibit knickpoint migration. The control life of these outcrops varies with unit thickness and flow conditions; relatively thick outcrops of one or more meters have persisted for several tens of years whereas thinner outcrops have failed in shorter periods of time. The third and youngest unit which limits knickpoint migration is the basal phase of the massive silt. The control life of these sills is several years, with failure usually resulting from the development of chutes through the polygonally structured basal phase followed by block disarticulation. An unusual feature of this type of knickpoint migration is the development of scour holes upstream of the sills. The scour holes frequently have bed elevations two or more meters below sill outcrop elevations (Grissinger and Murphey,1983).

In Goodwin Creek, the consolidated sandstone crop out throughout the channel and gravel bed material is common. Knickpoint movement and entrenchment on Goodwin have been minor. The channel has three functional segments with transition reaches. These transition reaches are defined by a relatively small knickpoint in reach 8 and by the presence of pre-Quaternary (see Stratigraphy section, Figure 4.3) bed and bank materials upstream of reach 18-1 (Figure 4.6) (Grissinger and Murphey,1983).

Table 4.2 Mean Soil Strength Parameters*

Soil	Cohesion (kPa)	Friction Angle (degrees)	Bulk Unit Weight (kNm^{-3})	Tensile Strength (kPa)
Tommy Florence Site (lower Johnson Creek)				
PSA	40.2	19	17.9	5.6
YP	62.0	25	18.4	5.1
OP	66.2	24	19.1	15.7
Silty/sand	3.9	40	21.2	0
T.A. Woodruff Site (upper Johnson Creek)				
PSA	31	29	17.0	8.5
YP	46.3	18	18.4	5.1
OP	80.0	18	20.3	32.6
Silty/sand	4.0	40	21.0	0
Katherine Leigh Site (lower Goodwin Creek)				
PSA	31.0	21	15.5	4.1
YP	40.0	20	16.9	10.1
OP	104.5	12	19.0	25.2
Silty/sand	5.0	40	21.1	3.7

* Areas in and in close proximity to Goodwin Creek

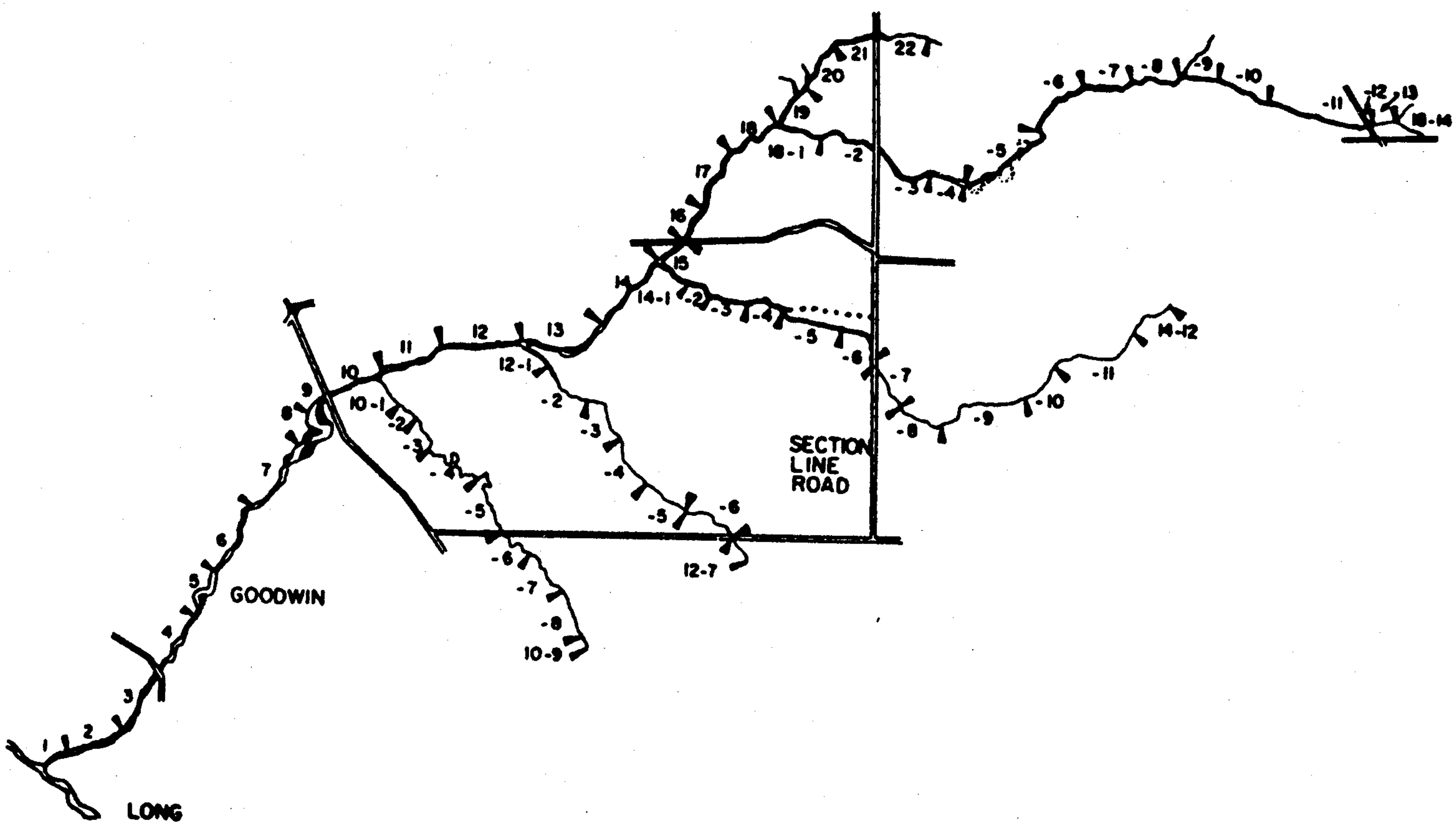


Figure 4.6 Goodwin Creek Reaches

4.6 Channel Surveys

In 1977, the Corps of Engineers, Lower Mississippi River - Vicksburg District (COE, LMKVD) contracted with a number of engineering firms to make "Streambank Erosion Surveys" of the channels in a number of Yazoo River Basin Watersheds. This activity was part of the Section 32 Program of Public Law 93-251 entitled the "'Streambank Erosion Control Evaluation and Demonstration Project". Hundreds of miles of channels were surveyed in this project as a part of Job #1532 and topographic maps were drawn for these channels at a 1::500 scale. Among the channels surveyed was Goodwin Creek in Panola County Mississippi. The Goodwin Creek survey resulted in 36 sheets of topographic maps drawn from hundreds of cross sections arrayed along base lines laid out along the top banks of the streams. The cross section data collected are located in field survey books which are on file at the Geodesy Section of the Vicksburg District Offices of the U.S. Army Corps of Engineers at P. O. Box 60, Vicksburg, MS. The surveys are in files numbered YYO-2-24, 25, 26, 27, 29 and 34. The National Sedimentation Laboratory at Oxford, Mississippi has photocopies of 43 of these Field Books. The books are labeled and numbered as F.B.: 25118, 25300, 26224, 26225, 26598, 26701-26707, 26709, 26713-26717, 26737-26745, 26748-26751, 26762-26765, 26779-26781, 26862, 27068, 27069 and 27427. These initial surveys are listed as series "A" in Table 4.3.

In 1980, some of the 1977 surveys were repeated in the lower end of the watershed by the COE. In November of 1982, the flumes and gaging instrumentation were being completed and the channels group at the National Sedimentation Laboratory wanted to monitor the sediment behavior in the lower portion of Goodwin Creek. Accordingly, the 1977 COE Survey base lines were re-established along the lower 3.2 km (2 miles) of Goodwin Creek and a number of the original cross sections were relocated and resurveyed. Of the original surveys, only every seventh cross section was in the reach was selected. The selected cross-sectional surveys of 1982 and the succeeding surveys are given in Table 4.3. Figure 4.7 shows the location and number of cross sections resurveyed in Goodwin Creek.

When survey #1 was completed in November of 1982, a baseline was established by W.S. Cook, R.L.S., ARS-NSL (retired) from the U.S.G.S. Benchmark (Q-16-23) at Eureka Springs, MS to the existing baselines on Goodwin Creek and the Goodwin Creek Watershed points. The points were tied into the MS State Plane Coordinate System using the North American Datum for 1927 (NAD 27) based on the Clarke 1866 spheroid. The "West" Mississippi baseline and Meridian were used (U.S.G.S. code #4376). All of the data in the "numbered" surveys in Table 4.3 have been reduced to MS State Plane cartesian coordinates. These X, Y, Z values are stored on computer tapes or discs at the National Sedimentation Laboratory. A summarization of this survey data is included on the attached CD Rom.

Table 4.3 Cross-Sectional Surveys of Goodwin Creek Watershed

Year Surveyed	Survey #	Survey Description
1977-1978 (May/Apr)	A-	Original COE survey (job #1532) performed as part of the Section 32 Program of Public Law 93-251. Thirty-six sheets of topographic maps of Goodwin Creek channels drawn at a 1::500 scale from 1050 cross-sections. The baseline is monumented with fifty-seven 3/4" square iron rods buried 6" below the surface of the ground. One hundred and seventy-one additional baseline hub positions are unmonumented but recoverable using the iron rods. The survey notes are in files numbered YYO-2-24, 25, 26, 27, 29, and 34 stored at the Geodesy Section offices of the Vicksburg District of the US Army Corps of Engineers at Vicksburg, MS.
1980 (Apr)	B-	COE repeated surveys of cross-sections C-1-1, C-2-1, C-2-5, C-3-2, C-4-8, C-4-17, C-5-2, C-5-6, C-5-10, C-6-6, C-7-4 and C-8-5.
1982 (Nov)	#1	ARS recovered baselines and placed iron pipe or iron pin monuments at each end of selected cross-sections. These were cross-sections: C-1-1-A (C-1-1 lost to bank erosion), C-2-1, C-2-5, C-3-2, C-4-8, C-4-17, C-5-2, C-5-6, C-5-10, C-6-6, C-7-4, C-8-5, C-10-1, C-41-3, C-42-3, C-43-2, C-45-1, C-46-1, C-47-2, C-50-1, C-52-1, T-1-1, T-2-2, T-3-5, T-5-A, T-7A, T-7A-RG, T-9, T-11-1 & T-12-3.
1983 (Feb)	#2-	Repeat of survey #1
1983 (May)	#3-	Repeat of survey #1

Table 4.3 Cross-Sectional Surveys of Goodwin Creek Watershed (continued)

Year Surveyed	Survey #	Survey Description
1983 (Jun/Jul)	#4-	Repeat of survey #1
1983 (Jul)	#4E-	Repeat of survey #1
1983 (Oct)	#5-	Repeat of survey #1
1983-1984 (Dec/Jan)	#6-	Repeat of survey #1
1984 (Mar)	#7-	Repeat of survey #1
1984 (Jul)	#8-	Repeat of survey #1
1984 (Sep/Oct)	#9-	Repeat of survey #1
1985 (Jan)	#10-	Repeat of survey #1
1985 (Apr)	#11-	Repeat of survey #1
1985 (Aug/Nov)	C-	New COE survey (Job #1775-01) with cross sections every 2500 feet monumented with a 3/4" square iron rod
1985 (Sep)	#12-	Repeat of survey #1, added GC-50 and GC-100 from survey C.
1985 (Dec)	#13-	Repeat of survey #12; dropped C-42-3 and T-5-A
1986 (Mar/Apr)	#14-	Repeat of survey #13; added T-14-2, T-14-6, T-58-4, T-60-1, T-60-5, T-62-1 and T-64-2.
1986 (Jun/Jul)	#15-	Repeat of survey #14
1986 (Sep)	#16-	Repeat of survey #14
1987 (Jan)	#17-	Repeat of survey #14
1987 (Mar)	#18-	Repeat of survey #14
1987 (Oct)	#19-	Repeat of survey #14
1988 (Feb)	#20-	Repeat of survey #14
1988 (May)	#21-	Repeat of survey #14
1988 (Jun)	#21A-	Repeat of survey #14
1990 (Mar/Apr)	#22-	Repeat of survey #14
1991 (Feb)	#23-	Repeat of survey #14

Table 4.3 Cross-Sectional Surveys of Goodwin Creek Watershed (continued)

Year Surveyed	Survey #	Survey Description
1992 (Feb\Mar)	#24-	Repeat of survey #14
1994 (Mar/May)	#25-	Repeat of survey #14; added surveys of thalweg, dike and waters' edge from Flume #1 to C-45-1
1995 (Feb/May)	#26	Recovered and resurveyed 51 additional 1977 cross-sections and repeated 20 cross-sections (*) from survey #14. These were: B-5-3, B-6, B-7-11, B-9-4, B-9-5, B-12-1, B-12-2, B-14-1, C-1-1(C-1-1A*), C-4-17*, C-5-10*, C-8-5*, C-10-1*, C-13-1, C-16-4, C-24-2, C-29-B, C-41-3*, C-45-1*, C-46-1*, C-50-1*, C-52-1*, C-53-2, GT-3-1-3, GT-3-3-7, JC-1-5, K-2-1, K-3-2, K-7-1, K-8-1, K-9-5, K-11-2, K-14-3, K-18-3, M-6-2, M-14-5, T-1-1*, T-1-3, T-4-3, T-5-A(GC-100)*, T-7-1, T-11-1, T-12-3*, T-14-2*, T-14-6*, T-17-2, T-20-1, T-21-1, T-21-2, T-22-3, T-23-2, T-24-3, T-26-2, T-30-9, T-35-A-1, T-36-1, T-40-2, T-42-2, T-57-2*, T-60-5*, T-62-1*, T-62-3, T-63-2, T-64-2*, T-64-3-B, T-67-2, T-72-2, T-72-3-C, T-75-1, T-77 and T-80-4.

The minimum, maximum, and average values for the width and depth for each reach are shown in Table 4.4. From the 1977 survey (Table 4.3), the channel widths and depths at point locations are highly variable and width-to-depth ratios are inconsistent. In addition, the width and depth are inversely related in reaches 1-7 (Figure 4.8) (downstream of the knickpoint) and upstream of reach 18-1 (Figure 4.9) where bank and bed materials are pre-Quaternary (see Stratigraphy section, Figure 4.3). Both of these regressions are significant at the 99% level. (Reaches 18-1 and 18-11 were not included; the former is transitional and the latter influenced by road-culvert control.) Depth is constant and independent of width for the middle segment (between reaches 8 and 18) (Figure 4.10) where thalweg elevation is controlled by the massive silt unit and by outcrops of the consolidated sandstone (Grissinger and Murphey,1983).

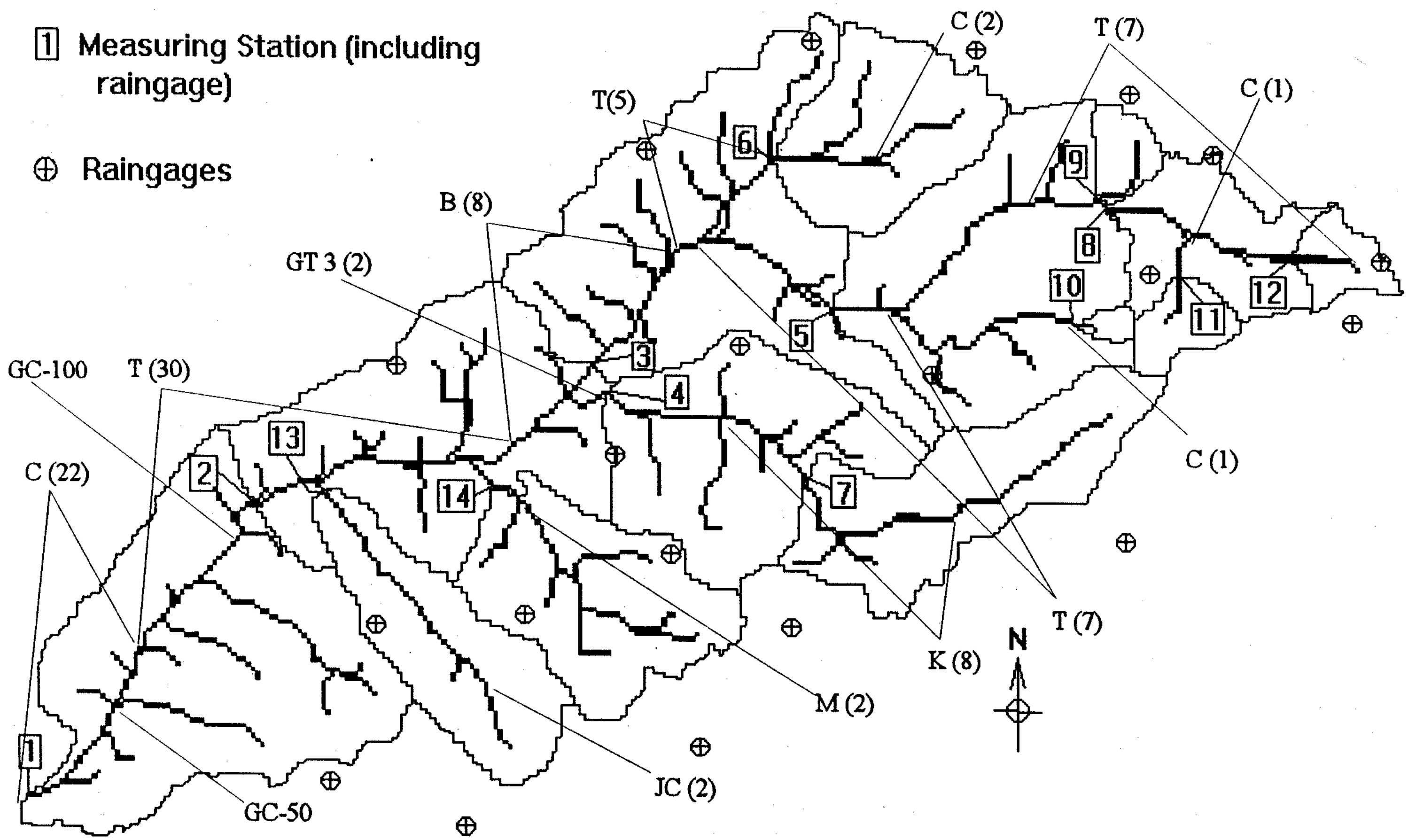


Figure 4.7 Location of Cross- Section Resurveys for Goodwin Creek
[Series prefix (number of cross-sections)]

Table 4.4 Width and Depth of Goodwin Creek Reaches, from 1977 Survey

Reach Number	Width (m)				Depth (m)			
	Max.	Min.	Avg.	Std Dev	Max.	Min.	Avg.	Std Dev
1	34.4	6.2	31.6	3.2	6.2	5.8	6.1	0.2
2	30.6	5.8	27.4	4.9	5.8	5.5	5.7	0.1
3	51.6	6	34.1	9.4	6.0	5.7	5.8	0.2
4	64.1	5.9	45.1	14.6	5.9	4.7	5.2	0.5
5	57.3	4.6	50.9	11.3	4.6	3.1	4.1	0.6
6	43.1	4.8	36.7	5.9	4.8	4.4	4.6	0.2
7	88.8	4.3	55.7	23.6	4.3	2.9	3.7	0.6
8	135.7	4.1	116.8	17.0	4.1	3.0	3.6	0.5
9	68.8	3.6	37.6	27.0	3.6	2.9	3.3	0.3
10	39.1	3.5	26.2	8.3	3.5	3.0	3.3	0.2
11	36	3.5	33.4	4.1	3.5	3.3	3.4	0.1
12	40.6	3.6	28.1	7.9	3.6	3.2	3.5	0.2
13	37.5	3.9	29.3	6.6	3.9	3.4	3.5	0.2
14	34.4	3.8	26.6	5.7	3.8	3.0	3.4	0.3
15	24.1	3.7	21.1	2.7	3.7	3.2	3.5	0.3
16	31.3	4.1	24.8	5.9	4.1	2.8	3.6	0.6
17	26.3	3.8	21.4	3.2	3.8	3.1	3.3	0.3
18	-----	-----	33.2	-----	-----	-----	3.5	-----
18-1	24.4	4.3	19.3	4.4	4.3	3.7	4.0	0.3
18-2	43.1	5.1	29.7	10.0	5.1	3.9	4.4	0.4

Table 4.4 Width and Depth of Goodwin Creek Reaches, from 1977 Survey (continued)

Reach Number	Width (m)				Depth (m)			
	Max.	Min.	Avg.	Std Dev	Max.	Min.	Avg.	Std Dev
18-3	45.3	4.5	29.6	9.2	4.5	2.8	4.0	0.7
18-4	35.4	4.4	31.4	5.2	4.4	4.0	4.0	0.2
18-5	27.4	4.8	22.5	3.9	4.8	4.6	4.7	0.1
18-6	27.4	16.8	22.2	4.0	-----	-----	4.6	-----
18-7	38.7	19.8	26.9	10.3	4.6	4.6	4.6	0.0
18-8	36.0	13.7	25.9	8.0	5.3	4.7	4.9	0.3
18-9	18.7	15.6	17.7	1.8	5.5	5.1	5.3	0.2
18-10	20.3	15.6	18.3	2.0	6.0	5.5	5.7	0.2
18-11	21.9	16.2	19.8	2.3	7.3	6.1	6.7	0.5

Thalweg slopes for these reaches are less than downstream reaches (Figure 4.11). (The slope for reach 8 was adjusted to remove the knickpoint drop at the lower end of this reach.) Grissinger *et al* (1983) believe that these two large bendways, which have apparently evolved from the interaction of channel modifications with valley-fill controls, at reaches 5 and 8, disrupt the downstream movement of coarse sediment and thus adversely affect downstream bank stability. Thalweg slopes throughout the remainder of the Goodwin Creek channel are locally controlled by the presence or absence of consolidated sandstone sills (Grissinger *et al*,1982) (Grissinger and Murphey,1983).

From interpretations by Grissinger *et al* at the National Sedimentation Laboratory, Goodwin Creek and channels in the area are not 'true' alluvial channels; they are not 'free to adjust' and are not composed of material identical with their present sediment load. The channel morphologies (dimensions, shapes, patterns and slopes) are controlled by the nature and distributions of the Holocene valley-fill deposits and several older materials. In addition, the morphology has not adjusted to the hydraulic regime. In this context, the present drainage system is immature and unstable. The system will change through time and this change is the long-term corollary of the present, relatively short-term bank and/or bed instability problems. For short term instability problems, the mechanism of failure and probably the rate of failure is related to the properties and distributions of the valley-fill or older materials (Grissinger and Murphey,1983).

The properties and distributions of pertinent valley-fill or older materials are not related to current environmental conditions. The functional control or influences of the bed and /or bank materials is constant for the watershed. These materials were deposited and modified by paleoclimatic conditions, primarily climatic and base level controls. In essence, these are relict controls with each control having a characteristic distribution. (Grissinger *et al*,1982).

4.7 Vegetative Control of Erosion

Streambank erosion is a common occurrence along many miles of streams and rivers throughout the United States and is considered a national problem It is estimated that 480,000 km (300,000 miles) of eroding streambanks in the United States produce approximately 450 billion kg (500 million tons) of sediment each year, or approximately 1,670 tons/mile per year. Research by the National Sedimentation Laboratory (NSL) has helped to establish the quantity of erosion that may occur in unstable channels (Bowie,1987). The computed yield from channel bank erosion was as much as 1,050,000 kg/km (1,860 tons/mi) per year. In Goodwin Creek Watershed, Grissinger et al. (1991) estimated that about 85 percent of the total sediment yield originated from the channel banks and bed (Bowie,1995).

If left unchecked, streambank erosion can become acute, resulting in astronomical losses of land and other property. In many sections of the U.S., this loss is valued at millions of dollars annually. In addition, sediment from eroded streambanks fills streams, waterways, and reservoirs, increases the potential for flooding and spoils the habitat for fish and wildlife. The removal of sediment each year from choked stream channels and reservoirs in this country is estimated to cost more than $250 million (Barnes,1968,1995).

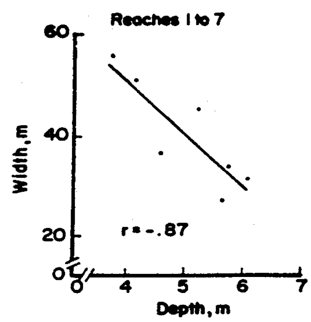


Figure 4.8

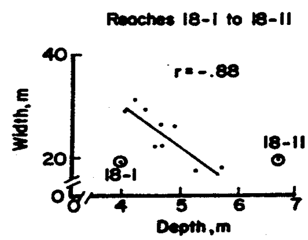


Figure 4.9

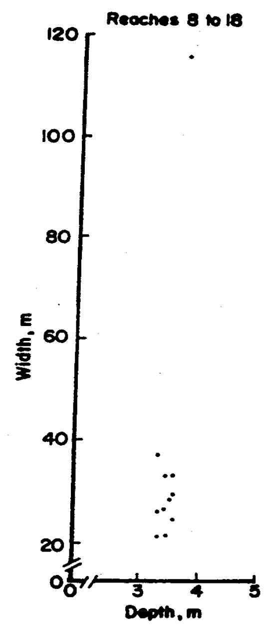


Figure 4.10

Figures 4.8, 4.9, and 4.10 Average widths and depths for Goodwin Creek reaches by process control groups, from 1977 survey.

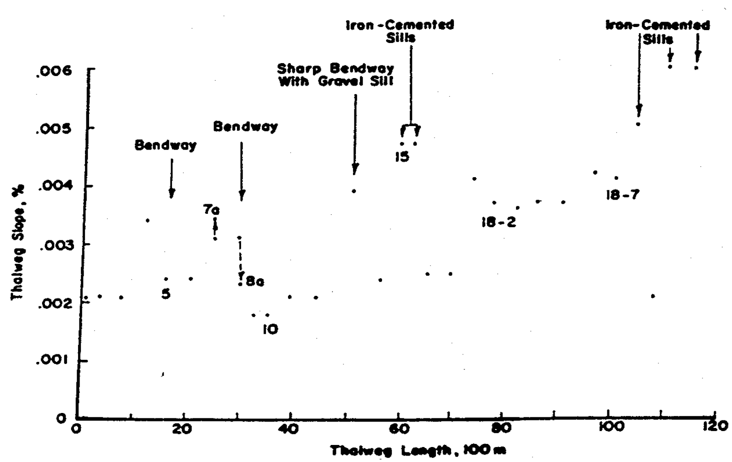


Figure 4.11 Thalweg profile for Goodwin Creek, from 1977 survey

4.7.1 Vegetative Control of Bank Stability

Effective streambank-protection measures have been costly to install and to maintain. A report by the Chief of Engineers (1969) to the Secretary of the Army indicated that the treatment of many of the damaged areas could not be justified, because the treatment at that time consisted primarily of costly structural materials. The report stated that research programs were needed to develop cheaper and more effective methods of treatment. In cooperation with the COE and NRCS (SCS), the NSL initiated studies on Goodwin Creek and Johnson Creek, an adjacent watershed to the north, to determine the feasibility of using vegetation to help stabilize eroding streambanks (Bowie,1981,1982,1995).

For vegetation used in this study, the time required to reach maturity or the stage of maximum production varied greatly, depending on the species and the growth environment. To establish good ground cover, at least two growing seasons in a good environment with the proper balance of soil moisture and plant nutrients were required for many of the grasses. It was determined at the beginning of the vegetative studies that 8 to 10 growing seasons would be required before a complete evaluation of material performance could be obtained. This decision was contingent on the need for recurring cycles of meteorological conditions to fully test the survival and protective characteristics of the various vegetative and structural materials. Construction was completed in late 1979 and in 1981.

Three vegetative study locations (Figure 4.12) were selected in two channels to test the performance of various plant species in conjunction with bank shaping with and without structural materials. The Goodwin Creek study reach was located in a 139 meter (456 ft.) channel reach with alternating bends. Several combinations of treatment were included along the concave and convex banks. The banks averaged 3.2 meters (10.6 ft.) high, and channel bottom widths were 9 to 12 meters (30-40 ft.). The bed gradient was approximately 4.9 m/km (26 ft/mi.). The catchment area above the study reach is 14 km^2 (5.4 mi^2) (Bowie,1995).

On Johnson Creek, two locations were selected, Johnson 1 and Johnson 2. The reaches are separated by a highway with site 1 on the upstream side (Figure 4.12). Reach 1 was 183 (600 ft.) long and curved. Several combinations of treatments were used along the concave (outside) bank while a continuous single treatment was used along the convex (inside bank). Site 2 was 496 m (1,627 ft.) long and straight. Several combinations of treatments were used along both banks. The banks in each reach averaged 4.5 m (15 ft.) high and the channel bottom width was 6-11 m (20-35 ft.). Before treatment, the bed gradient averaged 3.5 m/km (18.5 ft/mi.). However, due to the installation of a grade-control structure downstream, the gradient for reach 2 was reduced to 1.5 m/km (7.9 ft/mi.). The catchment area above the reaches is 16 km^2 (6.2 mi^2) (Bowie,1995).

4.7.2 Selection of Control Measures

A variety of control measures for stabilizing eroding streambanks are available. The type of protection needed for a specific case is largely determined by the characteristics of that channel. Factors to be considered in selecting the control measures include the height of bank, stability of bank material, stability of channel bottom, channel width, curvature of stream, bed gradient, availability of protective materials, use of property adjacent to the channel and allotted resources and cost of their implementation.

4.7.3 Vegetation

Because structural treatment is expensive, vegetation should be used to the fullest extent possible. The purpose of the vegetation is to provide a permanent dense cover that will prevent erosion of the channel banks but not overly restrict the channel capacity. The maximum use should be made of native vegetation. Suitable vegetative materials must withstand any expected flooding, provide year-round protection, become well established under adverse climatic and soil conditions, be long lived, develop a root system that will withstand the drag force of streamflow on the plant tops, have branch characteristics with many stems emerging from the boundary surface, have tough resilient stems and branches, and require only minimum maintenance (Bowie,1995).

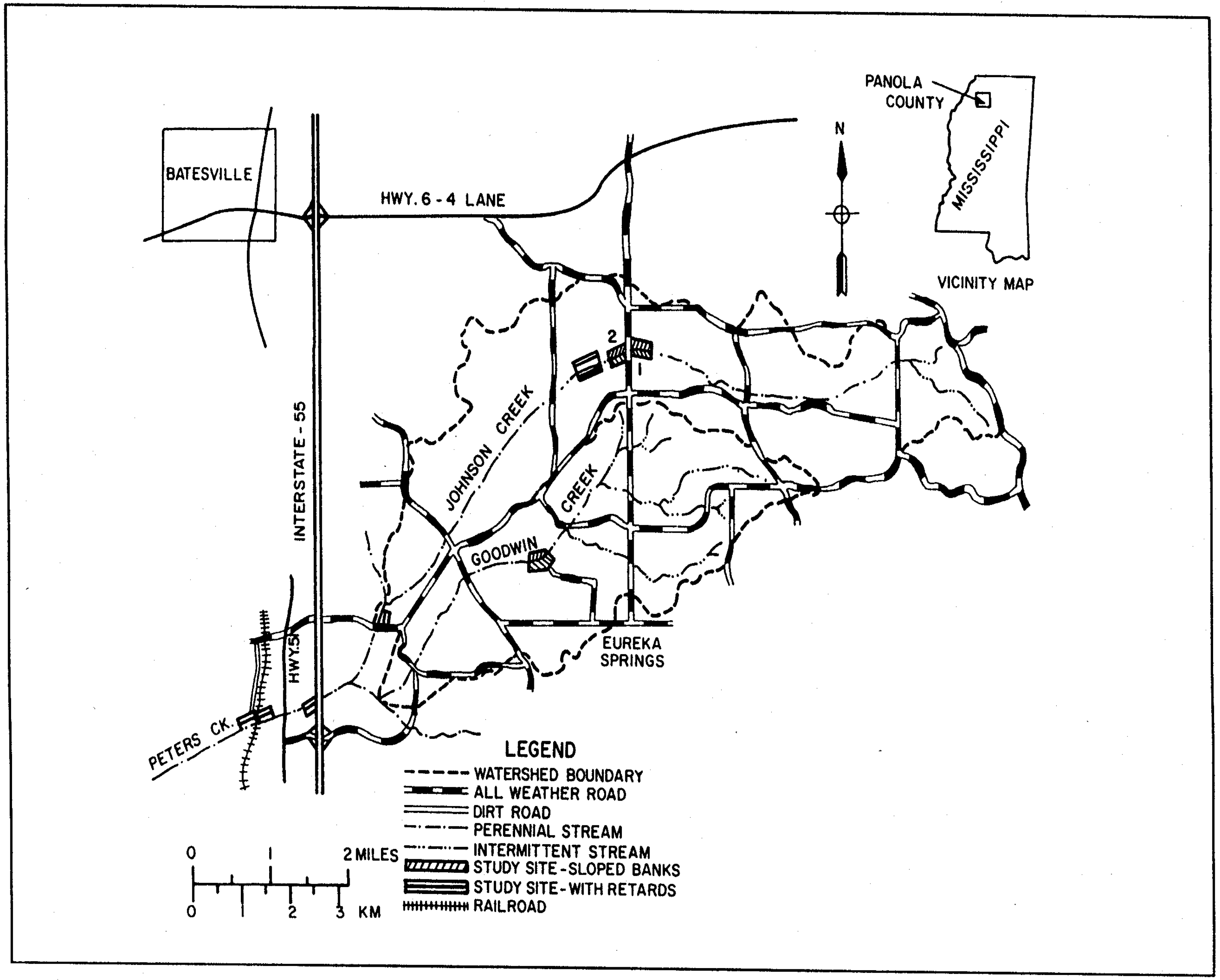


Figure 4.12 Location Map of Streambank Vegetative Study Area

Since most unstable channel banks have been eroded and undercut to a very steep unplantable slope, bank shaping is required for the satisfactory establishment of grassy species and many shrub-type woody species. The requirements of vegetation, soil stability, and maintenance dictate that bank slopes be not steeper than 2:1 (2m horizontal and 1m vertical). Site preparation for shaping, planting, and vegetation management becomes too difficult on steeper slopes. A slope of 2.5:1 to 4:1 should be used when possible. A slope of 2:1 on the lower bank adjacent to the channel toe is acceptable for the placement of flexible-type structural materials such as riprap and concrete-type blocks (Bowie,1995).

4.7.4 Vegetative Study Reaches

A variety of vegetative and structural materials were used on 28 different treatment sites to test the optimum combinations of material controls for each type reach (Bowie,1995). Table 4.5 lists the specific materials used in these studies. For more detailed information regarding specific treatments and maintenance practices, refer to Conservation Research

Report Number 43 (Bowie,1995). Site plans, cross sections, and before and after construction views for each reach are shown in Figures 4.13 through 4.27.

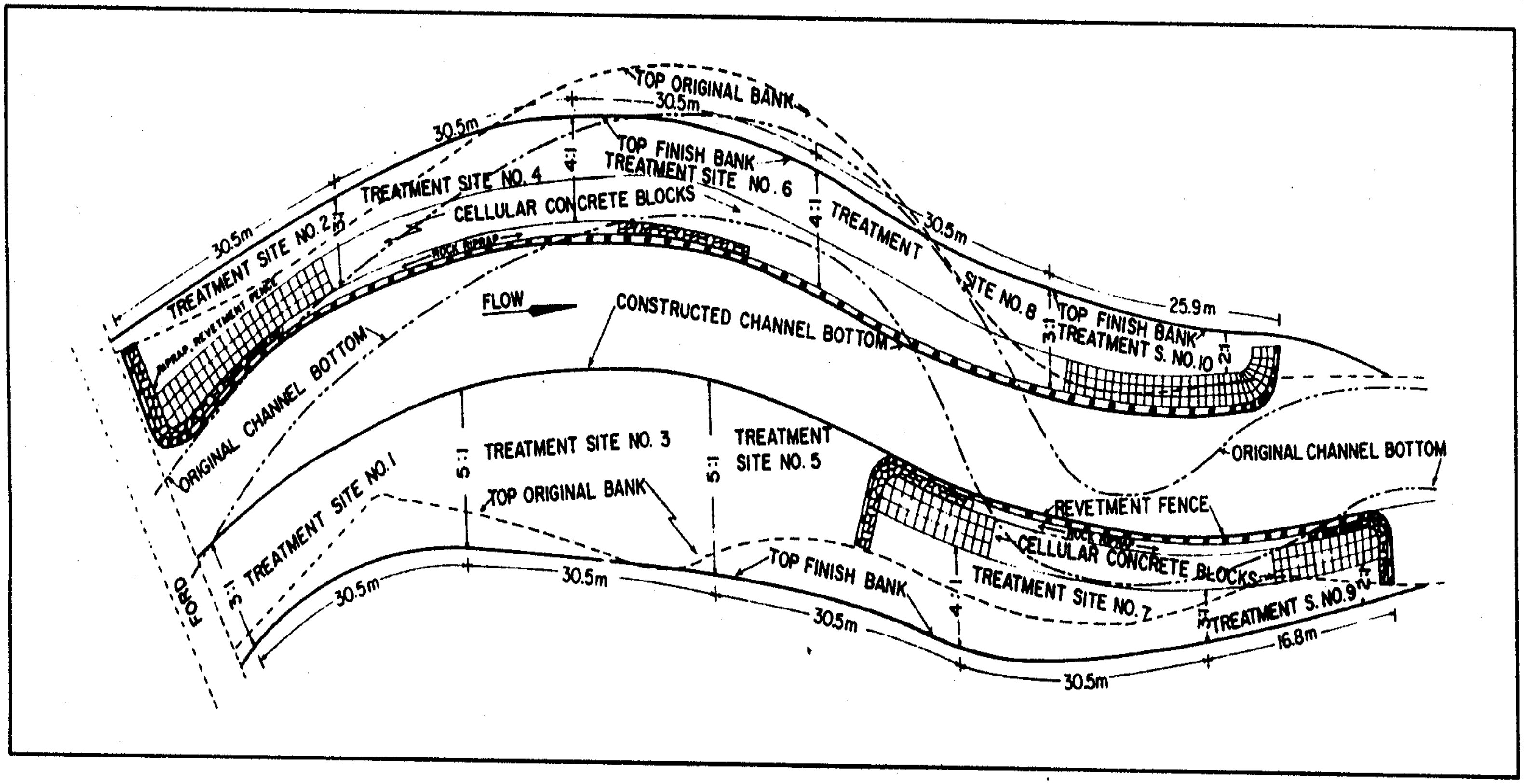


Figure 4.13 Site Plan of Goodwin Creek Study Reach

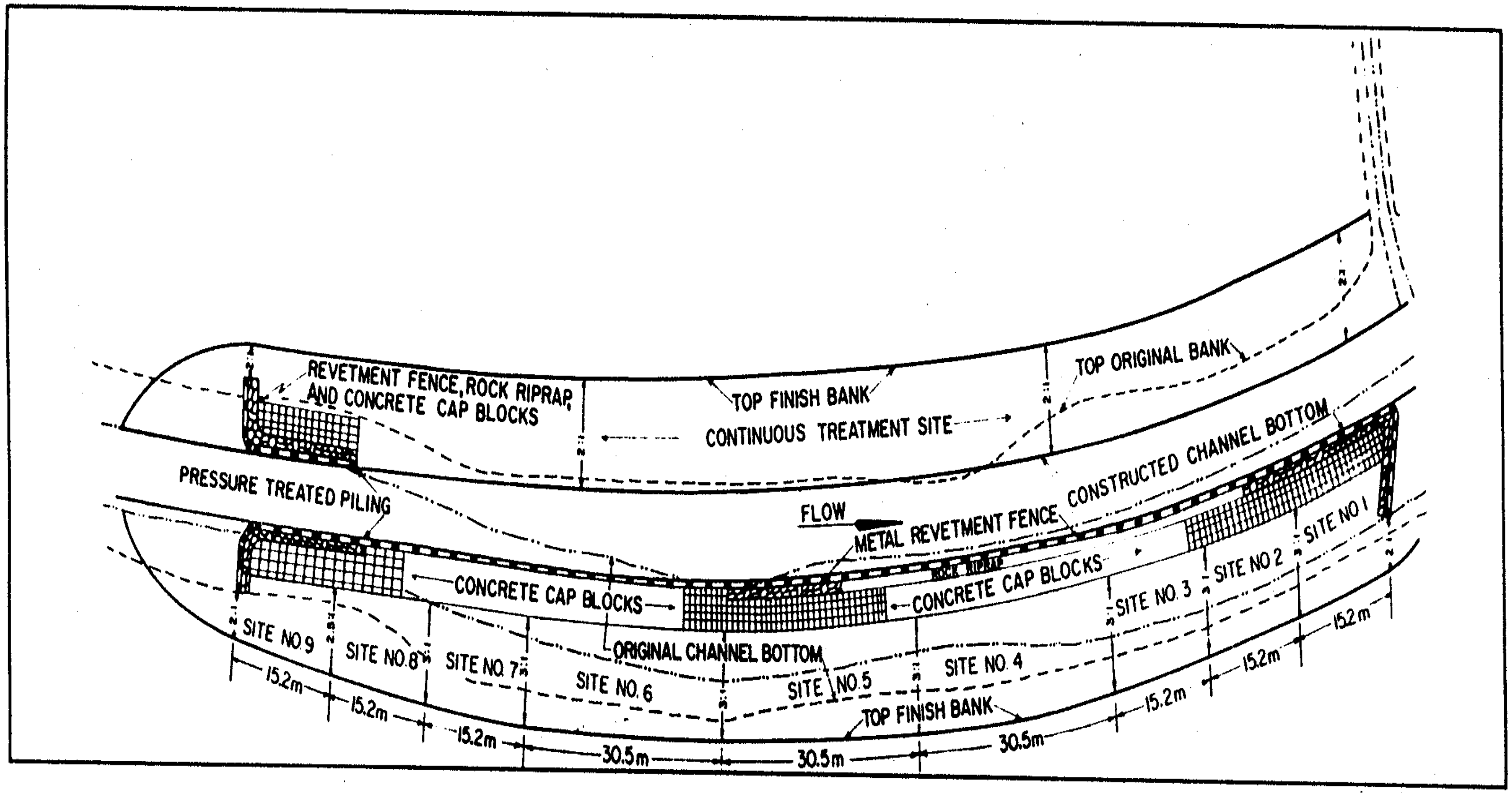


Figure 4.14 Site Plan of Johnson Creek Study Reach No. 1

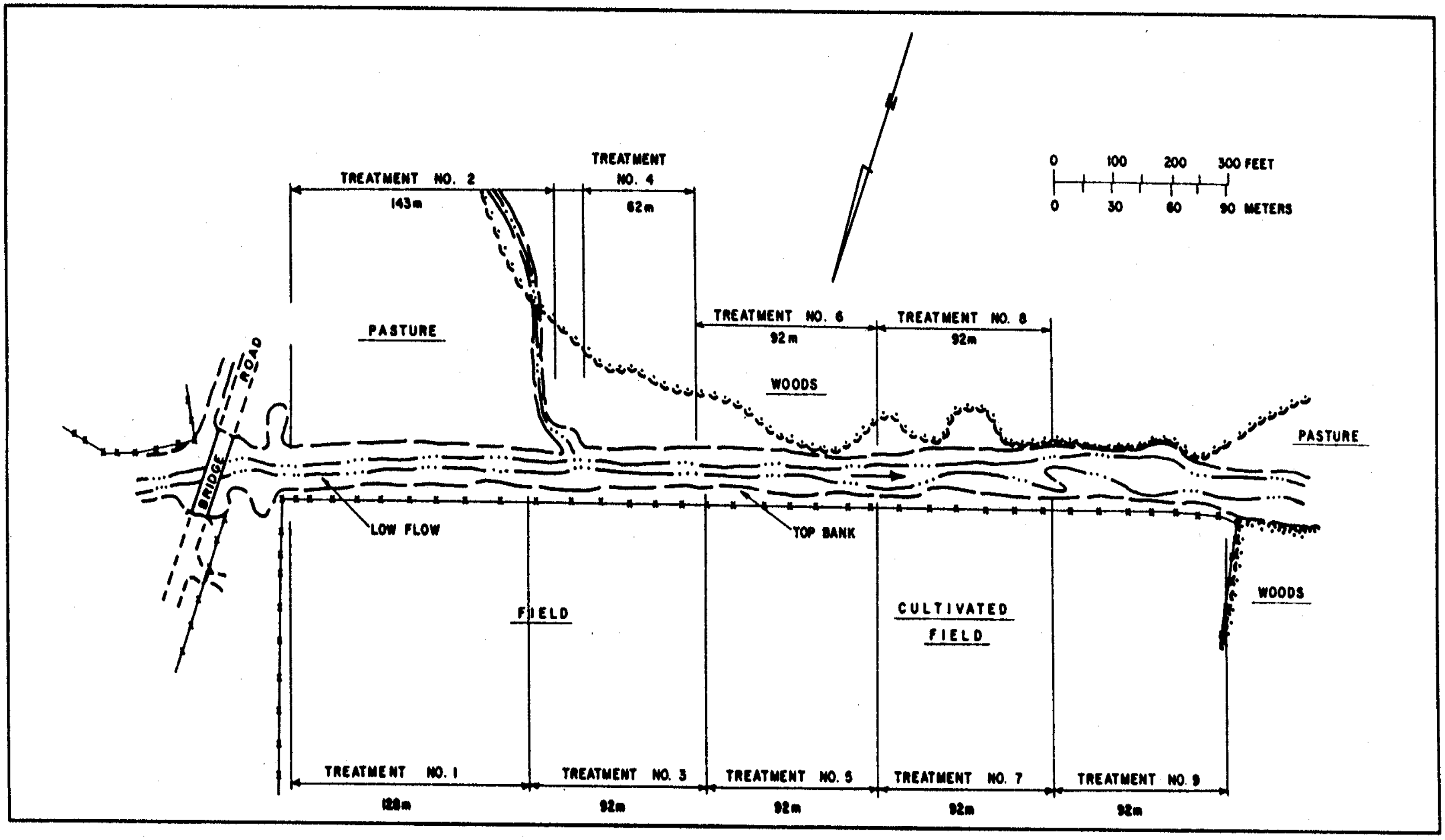


Figure 4.15 Site Plan of Johnson Creek Study Reach No. 2

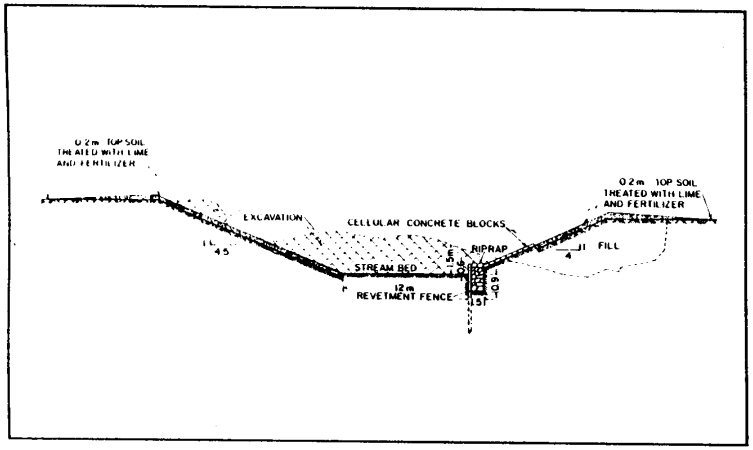


Figure 4.16 Cross Section of typical treatment of Goodwin Creek Study Reach

Figure 4.17 Downstream view of Goodwin Creek Study Reach before construction

Figure 4.18 Downstream view of Goodwin Creek Study Reach after construction

Figure 4.19 Downstream view of Goodwin Creek Study Reach after six growing seasons

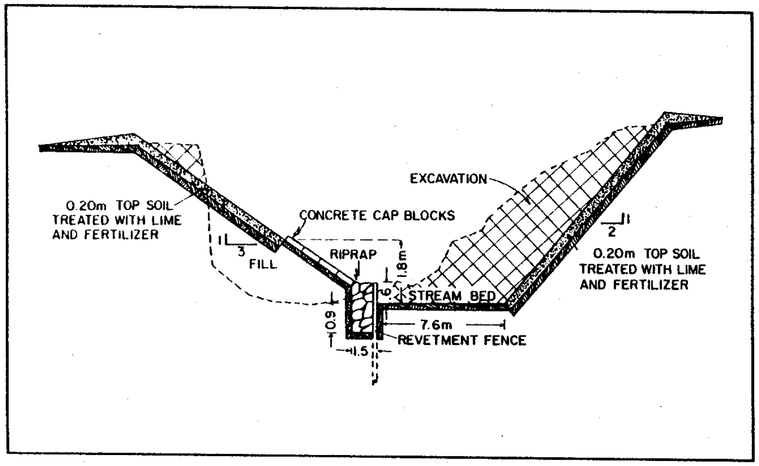


Figure 4.20 Cross Section of typical treatment of Johnson Creek Study Reach No. 1

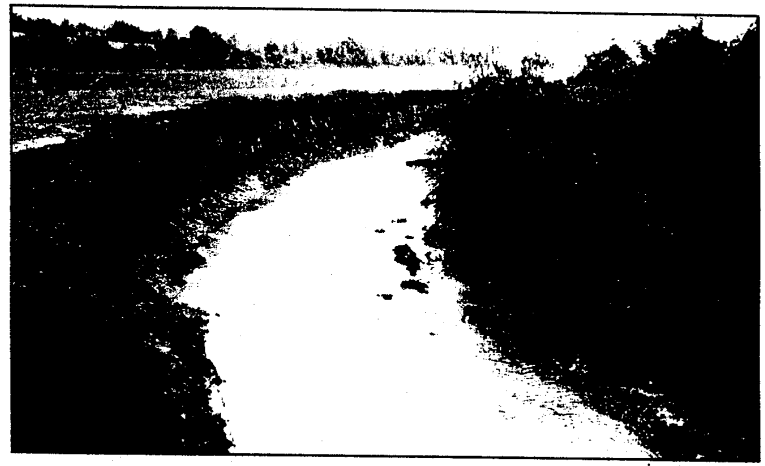


Figure 4.21 Upstream view of Johnson Creek Study Reach No. 1 before construction

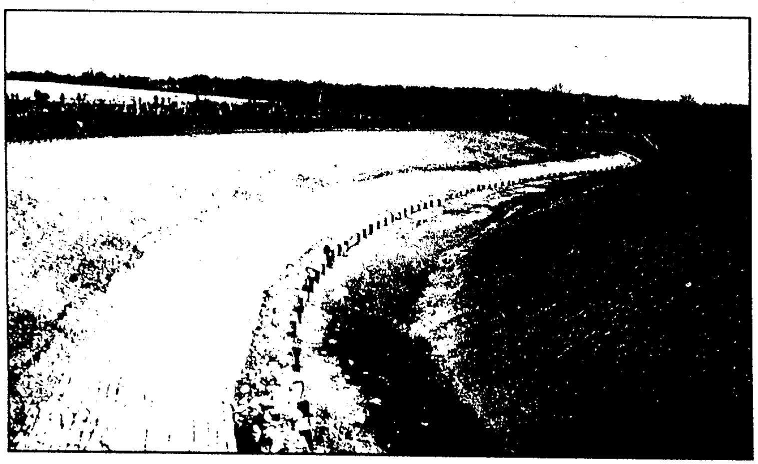


Figure 4.22 Upstream view of Johnson Creek Study Reach No. 1 after construction

Figure 4.23 Upstream view of Johnson Creek Study Reach No. 1 after six growing seasons

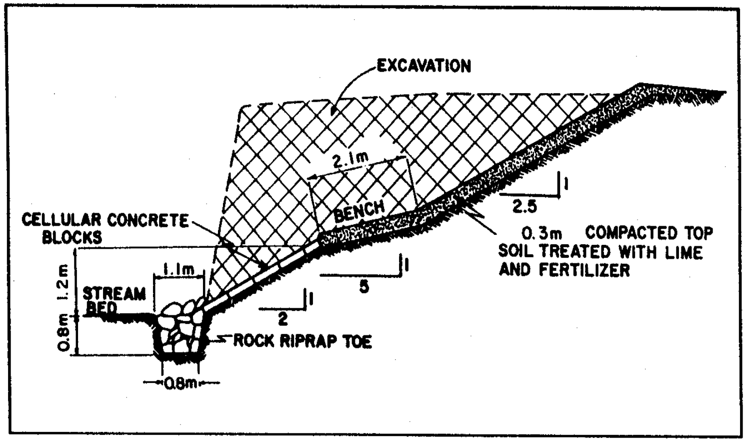


Figure 4.24 Johnson Creek Study Reach No. 2: Cross section of excavated bench, with lower bank and entrenched toe protected with structural materials

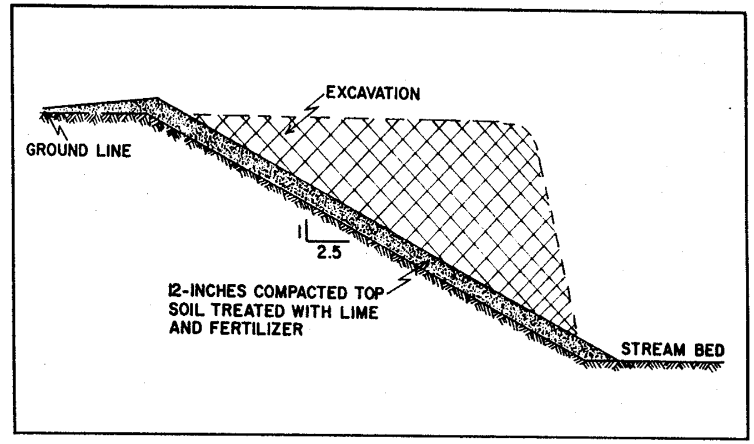


Figure 4.25 Johnson Creek Study Reach No. 2: Cross section of typical sloped bank without structural materials

Figure 4.26 Downstream view of Johnson Creek Study Reach No. 2 before construction

Figure 4.27 Downstream view of Johnson Creek Study Reach No. 2 after construction

Table 4.5 Materials Used for Stabilizing Eroding Streambanks

	Creek Study Reach		
Materials	Johnson No.1	Johnson No.2	Goodwin
Vegetative			
Alamo Switchgrass		X	X
Appalow serecia			X
Pensacola bahiagrass	X	X	X
Common bermudagrass	X	X	X
Black willow	X		X
Bristly locust	X	X	X
Boston ivy	X		X
Buffalograss	X		X
Crownvetch	X	X	X
English ivy	X		X
Indigo bush	X	X	X
False anil indigo			X
Halifax maidencane			X
Multiflora rose	X		X
Reed canarygrass		X	
Reedgrass, common			X
Sericea lespedeza	X	X	
Streamco willow		X	
Subterranean clover			X
Structural			
Stone riprap	X	X	X
Cellular concrete block		X	X
Concrete cap block	X	X	
Creosote piling	X		X
Chain link fence	X		X
Sand-clay-gravel mix		X	
Mulch			
Paper netting		X	
Wood excelsior blanket	X	X	X
Asphalt-emulsified wheat straw	X		X

4.7.5 Evaluation of Materials

The effects of the adverse meteorological conditions are reflected to some extent in the lower ratings for some of the vegetative materials shown in Table 4.6. The ratings in Table 4.6 are established on a scale of 1 to 9 (9 for best and 1 for worst). Evaluation ratings for herbaceous plants were determined from stand density, growth vigor, resistance to diseases and insects, and tolerance of inundation and adverse weather. The rating factors for woody plants included stand, growth vigor, abundance of stem and foliage, resistance to diseases and insects, and tolerance of inundation and adverse weather. The ratings factors for structural materials included cost and requirements for installation, degree of stability and protection provided, compatibility with vegetation, durability, and maintenance requirements. Mulch materials were rated primarily on the degree to which they prevented erosion (Bowie 1995).

Table 4.6 Evaluation* of Materials for Stabilizing Eroding Streambanks

Materials	Johnson No.1 Rating	Johnson No.2 Rating	Goodwin Rating	Overall Rating
Vegetative				
Herbaceous				
Alamo Switchgrass		7	9	9
Appalow serecia			1	1
Pensacola bahiagrass	3	5	5	5
Common bermudagrass	7	3	3	5
Buffalograss	0		0	0
Crownvetch	5	5	1	5
False anil indigo			3	3
Halifax maidencane			1	1
Reed canarygrass		1		1
Reedgrass, common			3	3
Sericea lespedeza	9	9		9
Subterranean clover			0	0
Woody				
Black willow	7		7	7
Boston ivy	0		0	0
Bristly locust	3	3	0	3
English ivy	0		0	0
Indigo bush	3	5	1	3
Multiflora rose	7		7	7
Streamco willow		0		0

* 9 = excellent, 7 = good, 5 = average, 3 = fair, 1 = poor, 0 = failure (or none).

Table 4.6 Evaluation* of Materials for Stabilizing Eroding Streambanks (continued)

Materials	Johnson No.1 Rating	Johnson No.2 Rating	Goodwin Rating	Overall Rating
Structural				
Stone riprap	7	7	7	7
Cellular concrete block		7	9	9
Concrete cap block	7	7		7
Creosote piling	7		7	7
Chain link fence	7		7	7
Sand-clay-gravel mix		1		1
Mulch				
Paper netting		1		1
Wood excelsior blanket	9	7	9	9
Asphalt-emulsified wheat straw	7		7	7

* 9 = excellent, 7 = good, 5 = average, 3 = fair, 1 = poor, 0 = failure (or none).

4.7.6 Vegetative Results and Conclusions

These studies showed that vegetation can be successfully used in a streambank- protection program and should be considered an integral part of the engineering design. Certain channel physical factors must also be considered and included in the design. Primary among these factors is stability of the channel bottom, which is usually a prerequisite for streambank stabilization. But before vegetation can stabilize bank erosion, it is necessary to check or eliminate scouring forces that degrade the channel bed. Often the failure of bank-protection work can be attributed to failure of the bank toe from scour, which in turn creates undercutting and sloughing of the upper bank. If it is possible that the bed may degrade, extra bank-toe protection should be included in the design criteria. This includes (1) excavating the channel bottom along the toe, deeper than any expected bed degradation, and (2) backfilling with stone rip rap (Bowie,1995).

If unstable channel banks have become severely eroded and undercut to very steep and unplantable slopes, bank shaping is required before vegetative materials can be planted. After shaping, the sloped channel banks should be treated with commercial fertilizer and lime, incorporated into the top 0.2 m (8 inches) of soil. The banks may then be planted with vegetative materials and covered with mulch to control erosion until vegetation establishes and develops. Maximum use of suitable native plants promotes better overall adaptation of vegetation. A mix of woody and herbaceous plants should be used to protect the soil surface, either by a very dense stand of shrubs or by shade-tolerant grass and legumes in a less dense stand of woody growth. Except for hardpoint areas, the use of structural materials on sloped banks may be required on only the lower section of the banks. The construction criterion for the height of structural revetment on a lower bank may be determined from the maximum depth of streamflow expected for 90-95 percent of annual storm events (Bowie,1995).

4.8 Watershed Characterization

To understand the morphological processes involved within a watershed, a complete data base is necessary. For Goodwin Creek, information concerning land use, soils, slope, aspect and drainage network have been compiled from a variety of sources such as NRCS (SCS) county soils maps, satellite imagery, digital elevation models (DEMs), global positioning system (GPS) derived coordinates, and topographic maps.

4.8.1 GIS Integration

With a variety of information, the data needed to be made more accessible and usable. To meet this goal, the data was used in conjunction with a geographic information system (GIS). A GIS is a computer software package which provides a powerful set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes. Geographical data describe objects from the real world in terms of their position with respect to a known coordinate system, their attributes that are unrelated to position, and their spatial interrelations with each other (Burrough,1990). At the NSL, two raster-based GIS packages are used, ERDAS and GRASS. The systems have provided a convenient and accessible data base for use in watershed analysis and modeling.

4.8.2 Ground Surveys

When Goodwin Creek Experimental Watershed was being developed, ground surveys were necessary to characterize the watershed for crop and cover condition and determine their influence. To effectively evaluate the land use in a systematic manner, each field was delineated using NHAP aerial photography and assigned a relative number based on the fourteen subwatersheds. These surveys have been conducted on a yearly basis to document temporal changes and analyze their effects. The classification used in the ground surveys has been divided into five categories: cultivated, pasture, idle land, forest and planted forest. The criteria used to define the crop and cover condition are explained by the following:

Cultivated land is divided into three categories: cotton, soybeans and small grain. The field classification is based upon visual confirmation of the crop or by asking the land owner. Types of crops are cotton, soybeans, corn, and small grain

Pasture is classified on the up-keep of the land, the presence of cattle, the presence of fences, and/or asking the land owner.

Idle land is classified on the up-keep of the land, if overgrown with scrub vegetation, the absence of cattle, no fences present, and/or asking the land owner.

Forest is classified on the age of the trees, an approximation of age is based on tree height and width which is usually seven years and older.

Planted forest is classified on the age of the trees; as with forest, an approximation of age is based on tree height and width. The range for the classification is from newly planted to seven years old.

In addition to crop and cover condition, information concerning percent slope, slope length and area was collected for each field. Also, each field's area has been calculated and defined on the basis of contributing and non-contributing to sediment production (Table 4.7). Non-contributing is defined as areas which drain into ponds, lakes, reservoirs, *etc*., while contributing is all other.

Ground surveys of Goodwin Creek for the period of record is given in Table 4.8. From the data and graphs (Figures 4.28, 4.29, 4.30, 4.31, and 4.32), the watershed has shown a decline in the amount of cultivated land with a corresponding increase in the amount of land in pasture and planted forest.

Table 4.7 Subwatershed Areas for Goodwin Creek Watershed

Watershed Number	Contributing Subwatersheds	Contributing Area (acres)	Non-Contributing Area (acres)	Total Area (acres)
1	1-14	4681	585.4	5266.8
2	2-14	3887	534.2	4421.6
3	3,5,6,8-12	1869	275.7	2145.0
4	4,7	781.8	111.9	893.7
5	5,8-12	951.7	81.6	1033.3
6	6	271.7	39.6	311.3
7	7	336.6	74.9	411.5
8	8,11,12	305.8	58.4	364.2
9	9	39.8	0	39.8
10	10	13	0	13.0
11	11	40.6	24.7	65.3
12	12	68.8	5.1	73.9
13	13	273.3	30.1	303.4
14	14	366.8	45.1	411.9

Table 4.8 Goodwin Creek Land Use*, 1984-1993

Land Use	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93
Cultivated	1006.8	816.3	702.2	798.8	583.4	616.4	581.1	678.4	658.3
Pasture	2392.0	2407.9	2388.5	2539.6	2606.5	2580.1	2565.1	2611.8	2626.4
Idle Land	502.9	677.5	811.0	563.3	711.8	659.1	662.6	513.4	491.7
Forest	1280.4	1280.4	1280.4	1280.4	1280.4	1280.4	1280.4	1276.2	1276.2
Planted Forest	84.7	84.7	84.7	84.7	84.7	130.8	177.6	187.0	214.2
Total	5266.8	5266.8	5266.8	5266.8	5266.8	5266.8	5266.8	5266.8	5266.8

* area values presented are in acres

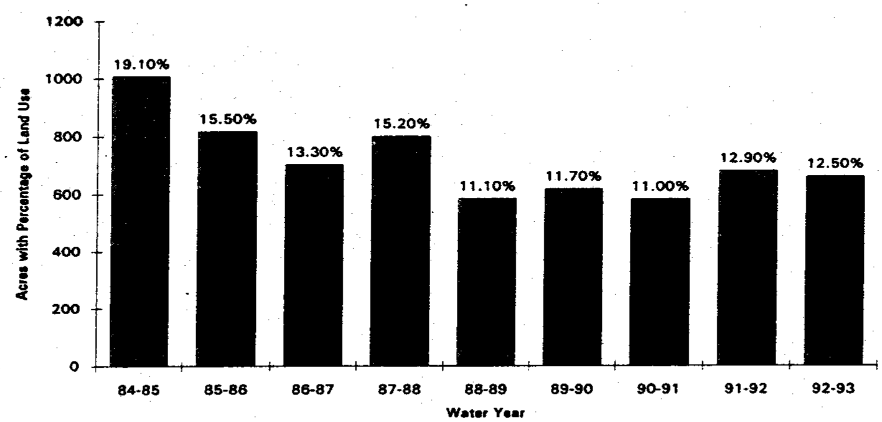


Figure 4.28 Cultivated Land Usage

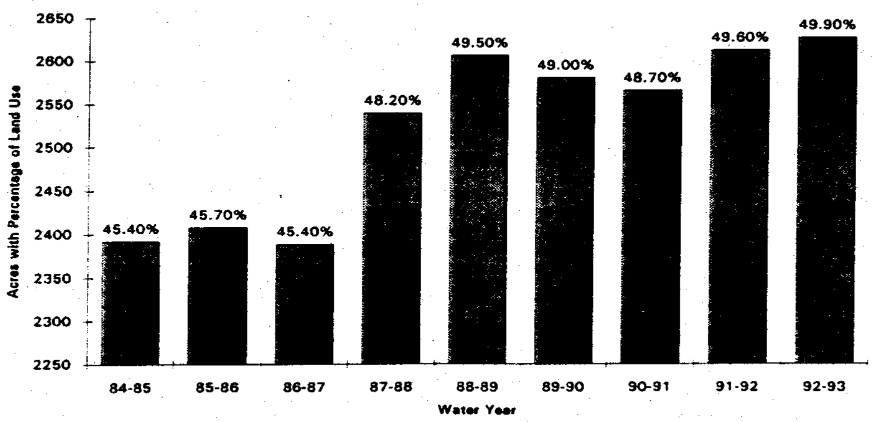


Figure 4.29 Pasture Land Usage

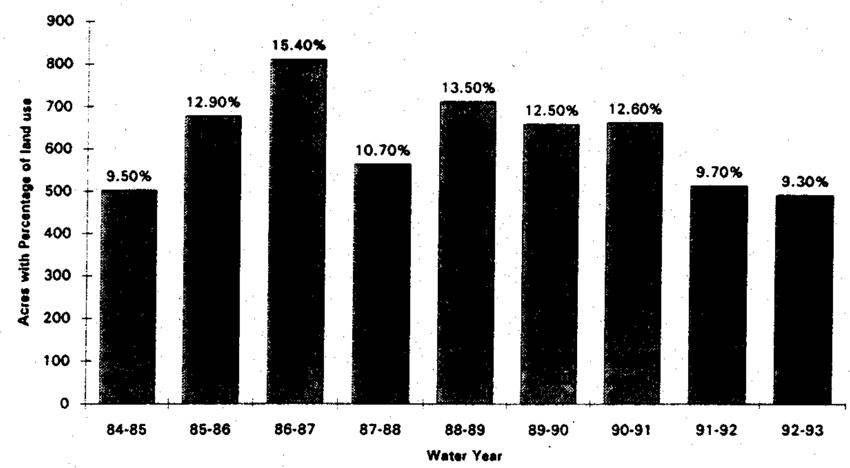


Figure 4.30 Idle Land Usage

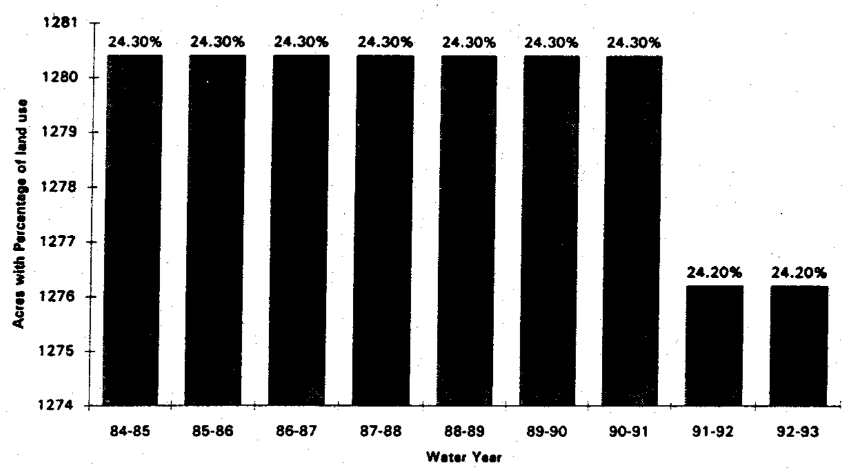


Figure 4.31 Forest Land Usage

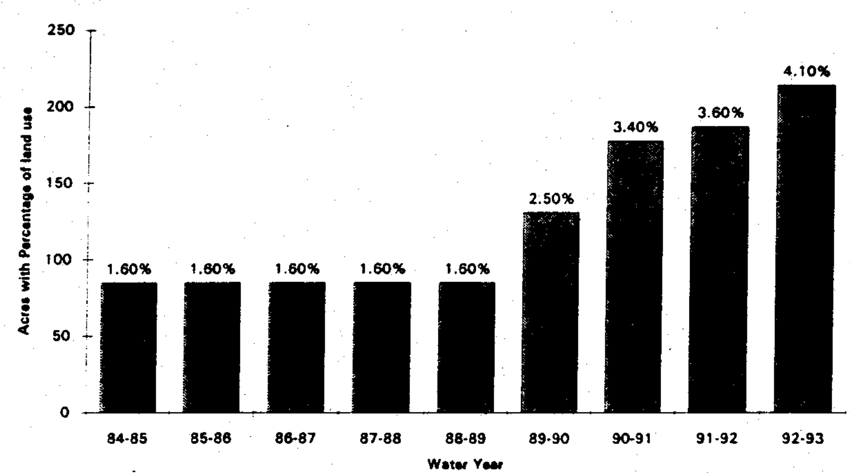


Figure 4.32 Planted Forest Land Usage

4.8.3 Land Use

Combining ground survey record, satellite imagery and a GIS, a land use map of Goodwin Creek was created. Forty representative fields of the 1987 ground survey were digitized and overlayed on a combined satellite image (Bands 4, 5, and 7) from the EROS Data Center. The identified fields were assigned to a classification scheme and classified using ERDAS. Based on the statistical characteristics of the image for each class, ERDAS created a classified map identifying areas within the watershed as cultivated land, timber, idle land-pasture and water (Figure 4.33) with percentage and acreage for each class. The classification scheme used in the GIS varies from the land surveys. The land surveys identify five cover classes which includes three types of cultivated land. However, statistical variations between similar classes were not large enough to allow for differentiation between cultivated lands (cotton, soybeans, small grains), idle land and pasture, and forest. Therefore, the classification scheme which combined idle land and pasture and forest and planted forest was used. Additionally, a water class was created which is not present in the land surveys. For the classification, water was made up of small ponds, lakes, and occasionally flooded fields. The land use map represents a computer-generated estimation of the vegetative cover for the watershed.

4.8.4 Soils

Soil Classification is an important part of the characterization of a watershed due to the inherent influences of soils and their spatial distribution on watershed hydrologic response, specifically, the nature and geotechnical properties of soils which effect particle detachment, infiltration, dispersion and transportation of water. Soils will also influence upland and channel erosion, channel bank and bed stability and, consequently, sediment yield within channels and from the watershed.

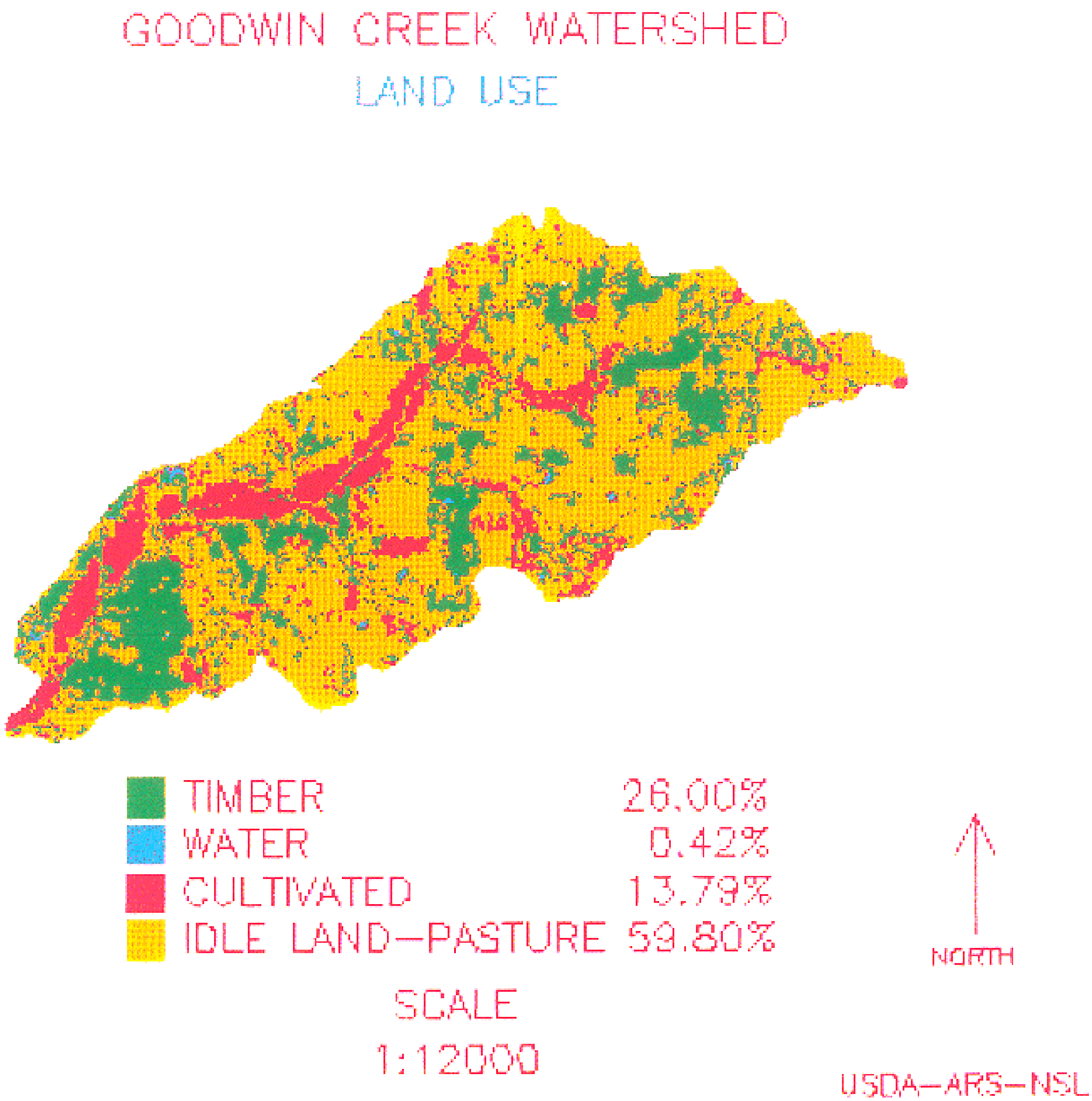


Figure 4.33 Goodwin Creek Watershed Land Use Map

The nature or composition of a soil is dependent on the parent material, climate, the degree and type of weathering, topography, and time. Some combination of these five factors determines the characteristics of each soil. Of these factors, the climate and parent material are usually the dominant factors of soil character.

In Goodwin Creek, the soils have developed in a climate that has consistently been hot and humid with slight variations over time (see Climate section). The parent material is derived primarily from a thick mantle of loess (silt transported and deposited by wind) and to a lesser degree sands and clays from Eocene Coastal Plain sediments and Mississippi River Pliocene and Pleistocene alluvial deposits. The soils are silty in texture and quite easily eroded when the surface vegetative cover is removed. Almost all of the soils erode as primary particles with very little movement as aggregates. This high erodibility has led to extensive gully development in the past with some areas of the watershed showing very high sediment yield as a result of these gullies.

The depositional environment under which the soils were formed is divided into two types of cycles, channel incision and channel widening. The cycle of incising or down-cutting by the streams occurs when sparse upland sediment sources are the limiting factor. The streams eventually reach a depth where mass bank failure limits the downward movement of the channels. The cycle of upland incision was initiated by the European settlement of the area between 1840 to 1880. Once cleared and cultivated, erosion of the loess mantle began and continued into the underlying sands. The overall effect of the actions of man, combined with nature filled the larger valley streams with sand. The over supply of sand temporarily stabilized the channel bed by burying a cycle of vertical incision then underway (the fourth such cycle in the last 10,000 years). When the presettlement channels had filled with sand, the eroded loess was able to be deposited as flows spread out-of-bank. The sand eroded from the uplands also was deposited as fans of colluvium at the sides of the valleys. Eventually, erosion of the uplands became so severe that upland row cropping was so dissected that it was no longer profitable. When this point was reached, many upland gullies and fields were put in pasture or planted in pine trees. This cut off the sediment sources over time and the cycle of channel-downcutting resumed. Once channels reached depths approaching the limits of vertical bank stability, they began to widen again.

The channel incision which is continuing at the present time is the fourth cycle within the Holocene period. The fine-grained cohesive component of the soils (i.e. clay and silt) that are detached in the uplands and channels are eroded and transported away by the streams, while the sands are deposited on the channel bed. With the absence of the fines, a layer of nearly sterile non-cohesive coarse grained soils (i.e. sand, gravel) are left on the beds. The coarse grained deposits or 'lags' in the valley fill deposits are believed to be Pleistocene to Holocene in age and were reworked locally from the ridges to the valleys. The absence of fine-grained soils in the beds has retarded growth of vegetation and led to a de-stabilizing of the channel banks which turn results in lateral movement (SCS (NRCS),1963)(Grissinger et al,1983).

4.8.4.1 Soil Distribution

The Natural Resources Conservation Service, NRCS, classifies soils based on the soil's characteristics. From their classification, soils are divided into series and associations. A series is a group of soils that have profiles almost alike. An association is a general map that shows several main patterns of soils based on their locality and arrangement. In Goodwin Creek, two major associations are mapped. The Collins-Falaya-Grenada-Calloway association is mapped in the terrace and flood plain locations. These are silty soils, poorly to moderately well drained and includes much of the cultivated area in the watershed. The Loring-Grenada-Memphis association has developed on the loess ridges and hillsides. These are well to moderately well drained soils on gently sloping to very steep surfaces and includes most of the pasture and wooded area in the watershed. It was these soils on the gently sloping ridge land that were first cleared and farmed in the 1840's and later abandoned or converted to pasture.

The associations consist of eight soil series which are described in Table 4.9 and their relative distributions per watershed and sub-watershed are given in Table 4.10. The distribution of soils was obtained from the NRCS maps (Figure 4.34) and processed using a geographic information system (GIS), ERDAS, Earth Resources Data Analysis System. The maps in Figures 4.35 and 4.36 were created using ERDAS and describe the soil series for Goodwin Creek. Figure 4.35 is a detailed soil series map describing the soils by name, slope percent and erosional condition. Figure 4.36 is a composite map of the watershed for each soil series (NRCS,1963).

4.8.4.2 Properties

From a slope stability analysis used to assess the stability of a streambank with respect to mass failure under gravity, many mechanisms of failure were identified as critical (Thorne *et al*,1981)(Little *et al*,1982). Failure depended on size, geometry and structure of the bank and the strength properties of the bank material. Data required for the slope stability analysis of the bank material included cohesion friction angle, tensile strength and bulk unit weight of the soil, and the heights and bank angles found in the field. Soil moisture content, usually found to be in the range of 15% to 35% dry weight during these tests, was also an important consideration from two standpoints, bank loading and strength alteration. To collect the data, three field sites were selected on two bluff line streams in Northwest Mississippi, two sites on Johnson Creek and one on Goodwin Creek (Figures 4.37, 4.38, 4.39, 4.40 and 4.41). All three are located in valleys of streams tributary to Long Creek, a tributary to the Yocona River, which exits the bluff line about four miles west of its confluence with Long Creek. All of the test sites were located in the valleys in the Collins-Falaya-Grenada-Calloway soil association (Figure 4.37). The site positions in the landscape are shown in Figure 4.38 which illustrates the topographic distribution of soils at each test site. Figures 4.39 through 4.41 show the location of the test holes at each site.

Table 4.9 Goodwin Creek Soil Descriptions

Soil Series	Description
Calloway (Ca)	Fine-silty, mixed, thermic Glossaquic Fragiudalfs; soils are somewhat poorly drained, strongly acid or medium acid silt loam soils formed in deposits of loess in upland positions of low relief (terraces). A fragipan is present generally at a depth of 16 inches.
Collins (Cm)	Coarse-silty, mixed, acid, thermic Aquic Udifluvents; soils are moderately well drained, strongly to medium acid, that have formed in silty alluvium on nearly level bottom lands. These silt loam soils occur primarily along the stream in the bottom area and are the location of much of the cultivation in the watershed. Cotton is the predominant crop but has been supplanted somewhat in recent years by soybeans.
Falaya (Fa)	Coarse-silty, mixed, acid, thermic Aeric Fluvaquents; soil consists of somewhat poorly drained, strongly to very strongly acid silt loam soils that developed in silty alluvium on nearly level bottom land. Most of the Falaya is cultivated.
Grenada (Gr)	Fine-silty, mixed, thermic Glossic Fragiudalfs; soil consists of moderately well drained, strongly to very strongly acid silt loam soils that have developed in thick loess deposits on uplands or terraces. A fragipan is present at a depth of about 24 inches.
Gullied Land (Gu)	Land consists of areas that are severely eroded, severely gullied, or both. The surface soil and much of the subsurface soil has been washed away. Most of this is land that was cleared, cultivated and later abandoned. It is now in trees, idle or pastured. It is unsuited for cultivation.
Loring (Lo)	Fine-silty, mixed, thermic Typic Fragiudalfs; soil series is moderately well drained to well drained, strongly to very strongly acid silt loam soils that developed in thick loess on uplands. A fragipan has formed at a depth of about 30 inches.
Memphis (Ml)	Fine-silty, mixed, thermic Typic Hapludalfs; soil series consists of well drained, strongly to very strongly acid silt loam soils that developed in thick loess on uplands. In Goodwin Creek, this soil occurs as a mixture with the Natchez and Guin or the Loring. This series has no fragipan within the characterization depth; it is predominantly wooded.
Mixed Alluvial Land (Mx)	Land is poorly drained to excessively drained, strongly acid silt loam and coarse sand; no uniformity in the arrangement, depth, color, or thickness of the soil layers. The soil is doughty and very low in organic-matter content and in natural fertility. It is in cultivation (row crops), pasture and trees (hardwoods).

Table 4.10 Goodwin Creek Soil Distribution Values as Percentage of Watershed Area in Soil Type

Soil Type/ Watershed	Calloway (Ca)	Collins (Cm)	Falaya (Fa)	Grenada (Gr)	Gullied (Gu)	Loring (Lo)	Memphis (Ml)	Mixed Alluvial (Mx)	Watershed Area (Hectares)
1	2.4	16.0	6.6	5.6	15.9	46.9	6.3	0.3	2160.72
2	2.2	17.6	3.7	6.3	15.6	50.2	4.2	0.2	1807.38
3	1.3	21.2	0.9	7.5	14.2	52.9	1.6	0.4	895.68
4	0.6	20.3	6.3	3.1	8.6	61.1	0	0	366.75
5	0	22.2	0	10.7	13.9	51.6	1.6	0	444.60
6	0	19.6	0	0	14.0	66.0	0.4	0	130.14
7	0	35.3	0	0	7.5	57.2	0	0	170.64
8	0	23.9	0	13.8	22.0	40.3	0	0	157.68
9	0	18.6	0	23.0	16.9	41.5	0	0	22.32
10	0	0	0	0	1.5	98.5	0	0	6.03
11	0	18.5	0	0	19.3	62.2	0	0	32.13
12	0	16.2	0	60.8	17.6	5.4	0	0	30.60
13	0	7.0	0	6.1	26.1	47.0	13.8	0	132.57
14	0	9.2	0	0.2	29.9	50.7	10.0	0	165.15

Table 4.11 Brief Description of Goodwin Creek Soils and their Estimated Physical Properties*

Soil Symbol	Slope Percent and Erosional Condition	Depth to seasonally high water table (feet)	Depth from surface (typical profile) (inches)	Classification (Unified)	Permeability (inches per hour)	Available Water Content (inches per inch of soil)	Reaction (pH value)	Dispersion	Shrink-Swell Potential
CaA CaB	0 - 2% 2 - 5%	1 - 2	0 - 6 6 - 11 11 - 16 16 - 50 50 - 60+	ML or CL ML or CL CL ML or CL ML or CL	0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 < 0.05 0.8 - 2.5	0.116 0.116 0.100 0.100 0.100	6.0 6.0 5.0 5.0 5.0	High Moderate Moderate Moderate High	Low High Moderate Low - Moderate Low
Cm Co	0 - 2% local alluvium, 0 - 3%	2 - 4	0 - 6 6 - 24 24 - 48+	ML or CL ML or CL ML or CL	0.8 - 2.5 0.8 - 2.5 0.8 - 2.5	0.125 0.116 0.116	5.5 5.5 5.0	High High High	Low Low Low
Fa Fl	0 - 2% local alluvium, 0 - 3%	0.5 - 2	0 - 7 7 - 43+	ML ML	0.8 - 2.5 0.8 - 2.5	0.125 0.125	5.0 5.0	High High	Low Low
GrA GrB GrB2 GrB3 GrC2 GrC3 GrD2 GrD3	0 - 2% 2 - 5% 2 - 5%, eroded 2 - 5%, severely eroded 5 - 8%, eroded 5 - 8%, severely eroded 8 - 12%, eroded 8 - 12%, severely eroded	2 - 10+	0 - 5 5 - 23 23 - 53+	ML CL ML or CL	0.8 - 2.5 0.8 - 2.5 <0.05	0.116 0.150 0.058	5.0 5.0 4.5	High Moderate Moderate	Low Moderate Moderate
Gs	gullied land, sandy	-----	-----	-----	-----	-----	-----	-----	-----
Gu	gullied land, silty	-----	-----	-----	-----	-----	-----	-----	-----

*Information taken from the USDA-NRCS Soil Survey, Panola County Mississippi (1963)

Table 4.11 Brief Description of Goodwin Creek Soils and their Estimated Physical Properties* -- (continued)

Soil Symbol	Slope Percent and Erosiona Condition	Depth to seasonally high water table (feet)	Depth from surface (typical profile) (inches)	Classification (Unified)	Permeability (inches per hour)	Available Water Content (inches per inch of soil)	Reaction (pH value)	Dispersion	Shrink-Swell Potential
LoB2 LoB3 LoC LoC2 LoC3 LoD LoD2 LoD3 LoE2 LoE3	2 - 5%, eroded 2 - 5%, severely eroded 5 - 8% 5 - 8%, eroded 5 - 8%, severely eroded 8 - 12% 8 - 12%, eroded 8 - 12%, severely eroded 12 - 17%, eroded 12 - 17%, severely eroded	5 - 20	0 - 5 5 - 33 33 - 54+	ML CL ML or CL	0.8 - 2.5 0.8 - 2.5 < 0.05	0.116 0.141 0.150	5.0 5.0 4.5	High Moderate High	Low Moderate Low - Moderate
MIF2 MIF3	17 - 35%, eroded 17 - 35%, severely eroded	10 -20	Memphis: 0 - 4 4 - 31 31 - 65 Loring: 0 - 5 5 - 33 33 - 54+	 ML CL ML ML CL ML or CL	 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 < 0.05	 0.116 0.141 0.150 0.116 0.141 0.150	 5.0 4.5 5.0 5.0 5.0 4.5	 High Moderate High High Moderate High	 Low Moderate Low Low Moderate Low - Moderate
MnF2	Memphis, Natchez, Guin, 17 - 40%, eroded	10 -20	Memphis: 0 - 6 6 - 25 25 - 49 49 - 60+ Natchez: 0 - 6 6 - 18 18 - 66+ Guin: 0 - 5 5 - 50+	 ML CL ML ML ML ML ML GM or SM GM or SM	 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 2.5 - 5.0 > 10.0	 0.116 0.116 0.150 0.150 0.116 0.116 0.150 0.058 0.058	 5.0 5.0 5.5 6.5 7.5 6.0 8.0 6.0 6.0	 High Moderate High High High High High High High	 Low Moderate Low Low Low - Moderate Low - Moderate Low - Moderate Low Low
Mx	Mixed Alluvial, 0 - 3%	1 - 3	-----	-----	-----	-----	-----	-----	-----

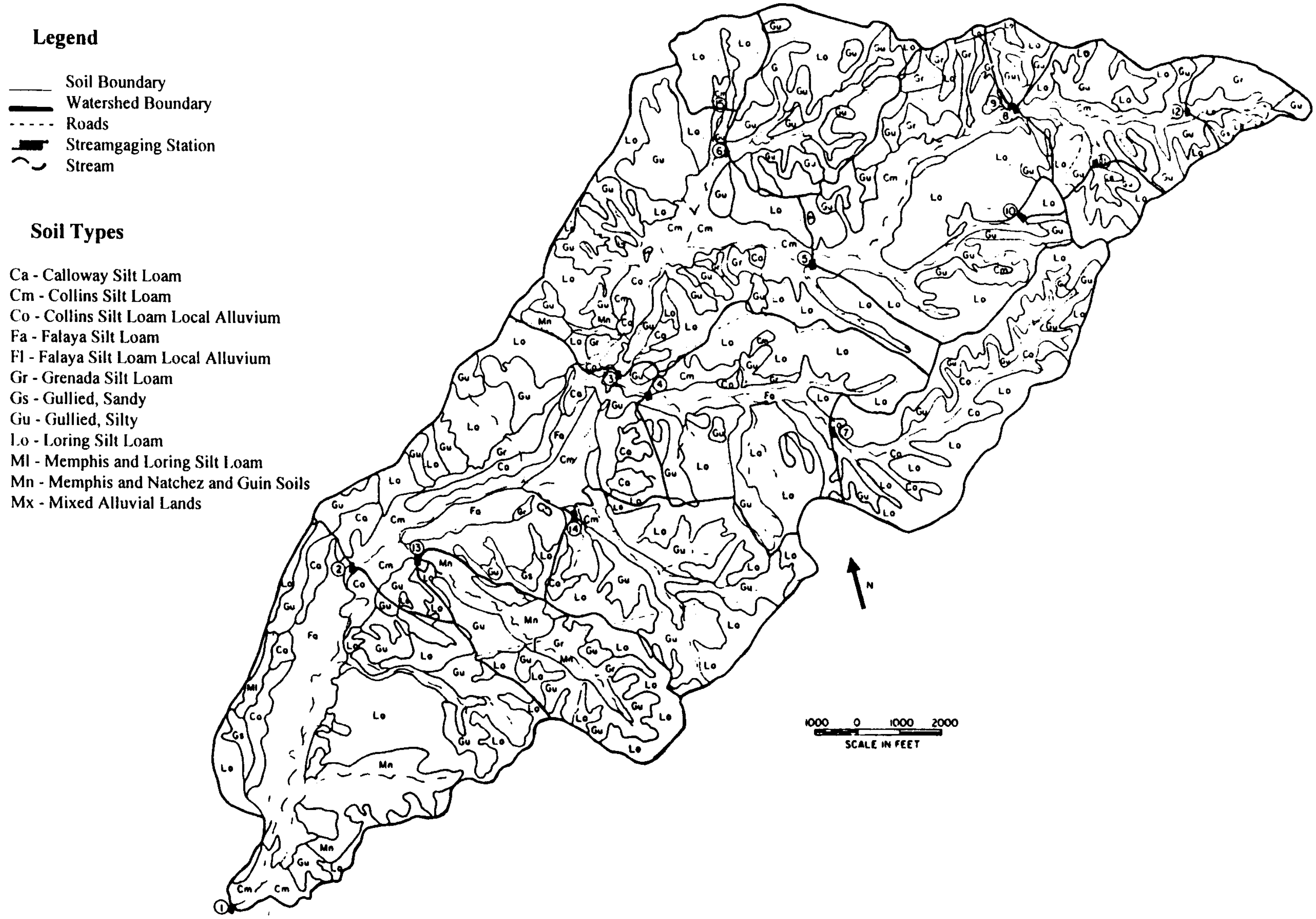


Figure 4.34 NRCS Soils Map of Goodwin Creek

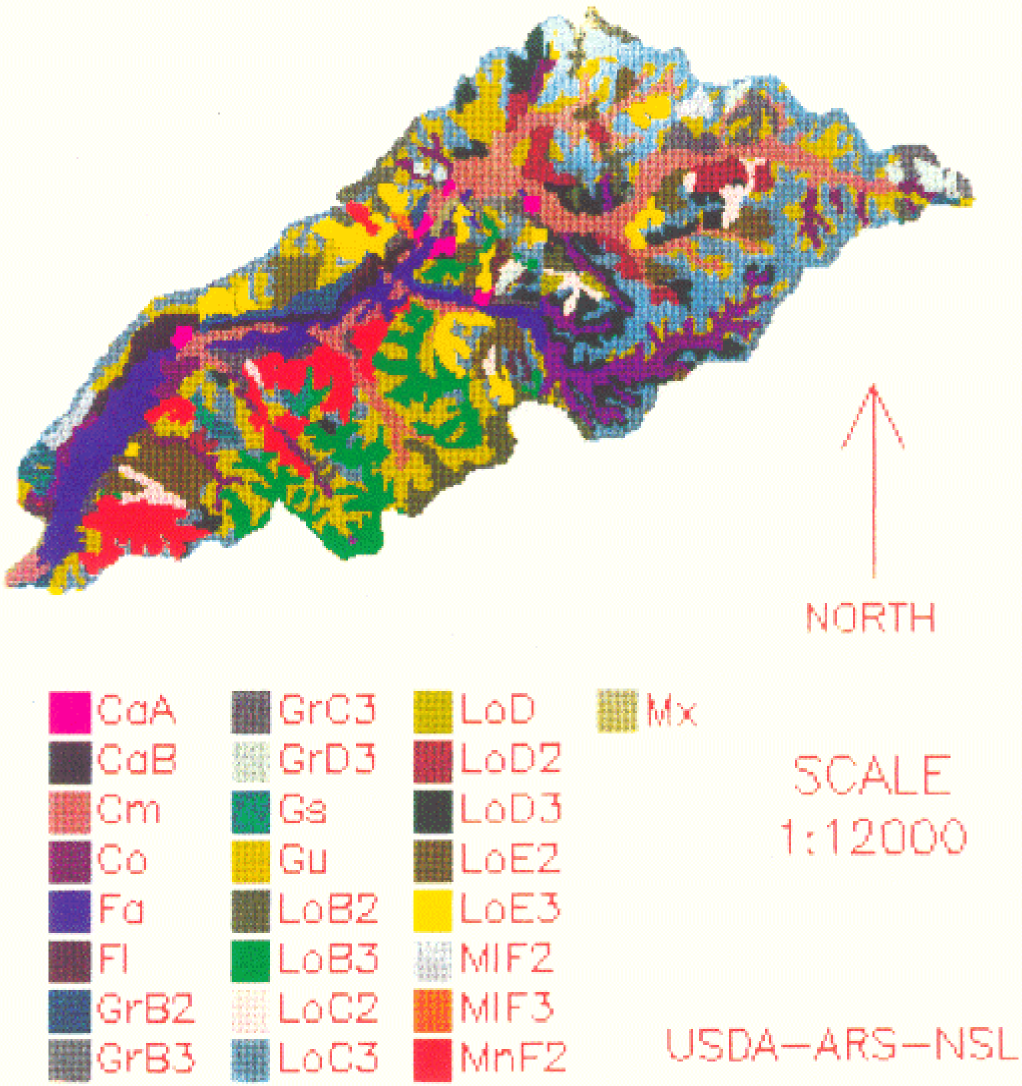


Figure 4.35 Soil Series Map of Goodwin Creek Watershed

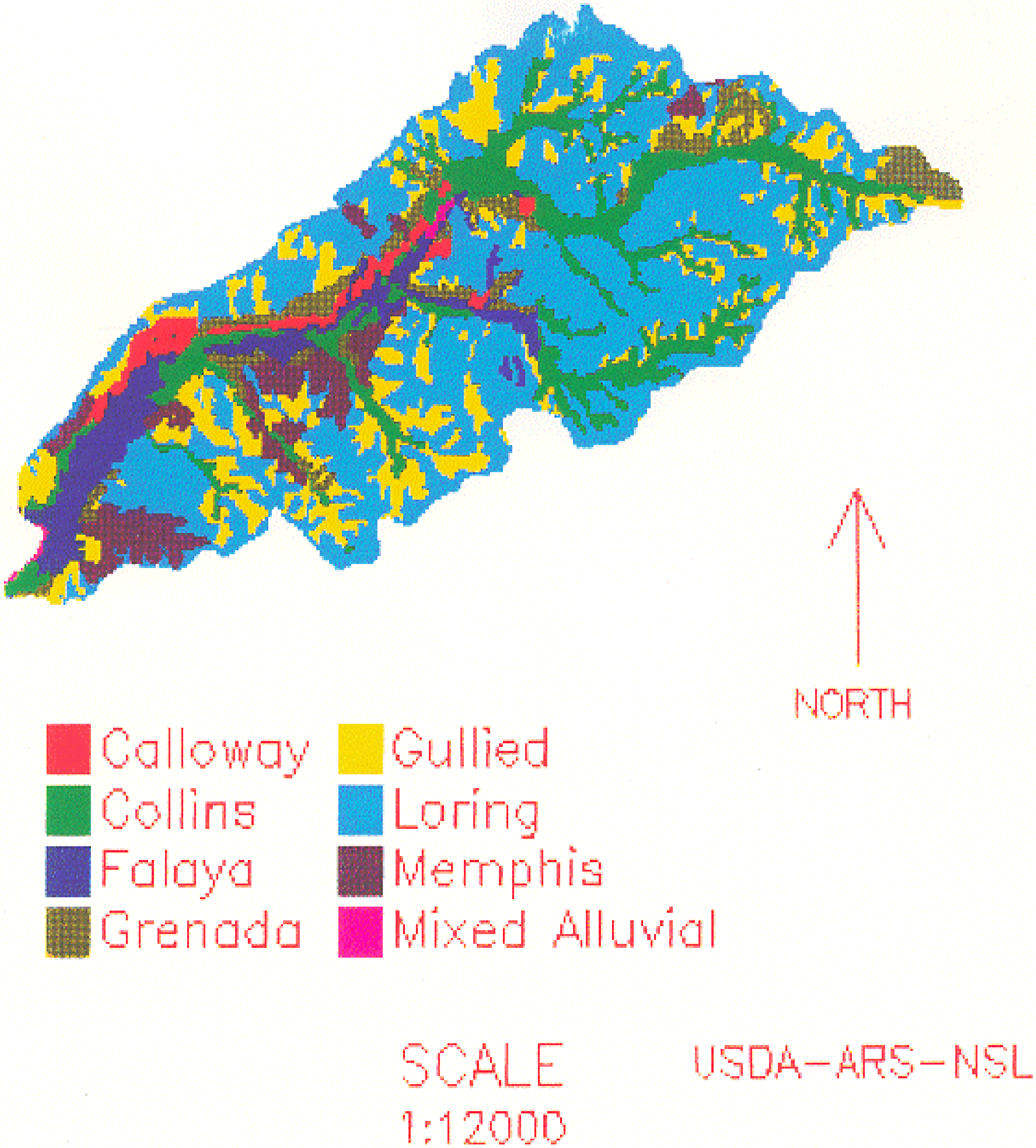


Figure 4.36 Composite Soil Series Map of Goodwin Creek Watershed

Material properties were determined by field and laboratory analysis and description of boring samples and from direct tests of shear strengths in situ in the boreholes utilizing an Iowa Borehole Shear Tester. Tests in the laboratory included Unconfined Compression tests, Triaxial Shear tests, and Unconfined Tension Strength tests. Material properties such as particle size distribution and moisture content were also determined in the laboratory. Results of these tests were reported in Thorne *et al*, 1981 and Little *et al*, 1982.

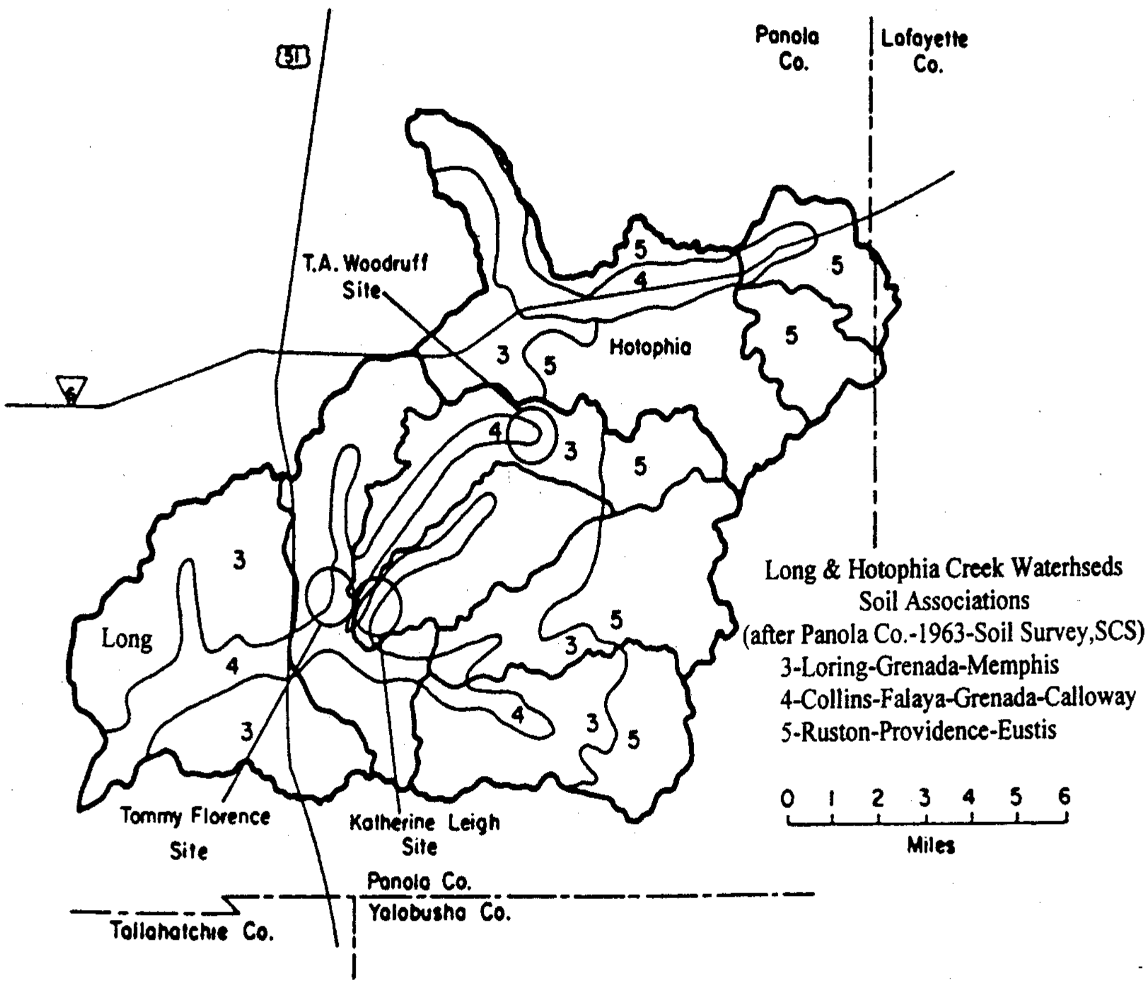
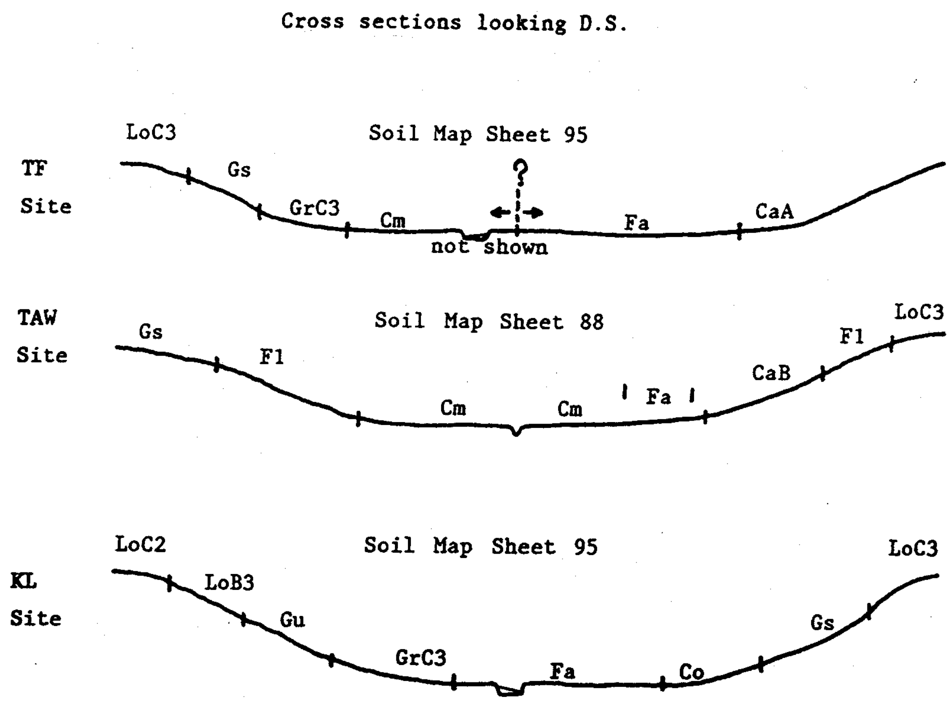


Figure 4.37 Geographic Locations of the test Sites shown on Soil Map of Area



Soils data taken from Soil Survey., Panola County, MS, Series 1960, No.10, (Dent,1963)

CaA	Calloway silt loam, 0-2% slopes
CaB	Calloway silt loam, 2-5% slopes
Cm	Collins silt loam
Co	Collins silt loam, local alluvium
Fa	Falaya silt loam
Fl	Falaya silt loam, local alluvium
GrC3	Grenada silt loam, 5-8% slopes, severly eroded
Gs	Gullied land, sandy
Gu	Fullied land, silty
LoB3	Loring silt loam, 2-5% slopes, severly eroded
LoC2	Loring silt loam, 5-8% slopes, eroded
LoC3	Loring silt loam, 5-8% slopes, severly eroded

Figure 4.38 Valley-Normal Soil Transects at each Test Site (schematic)

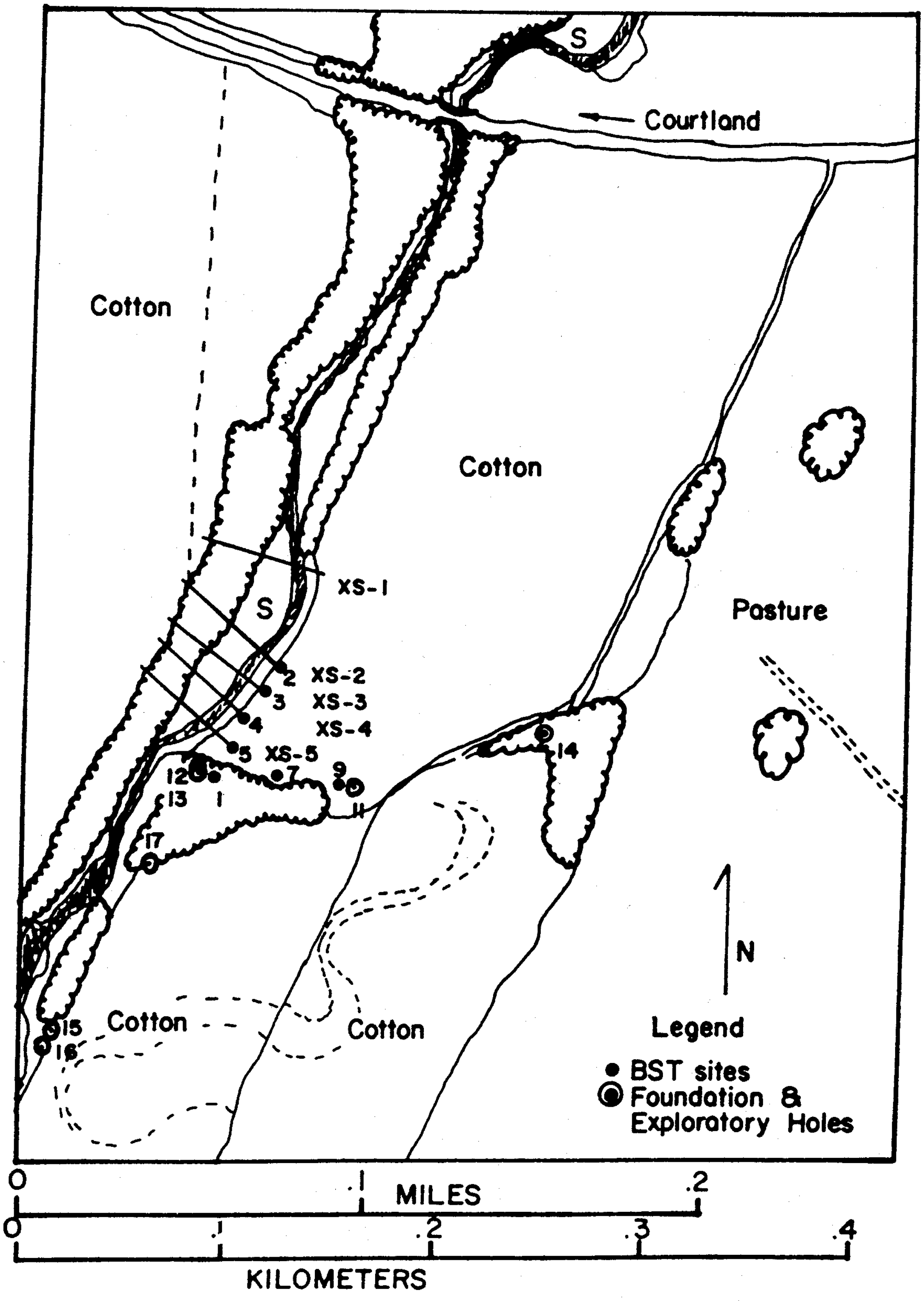


Figure 4.39 Locations of Florence Site Test Holes and Cross Sections

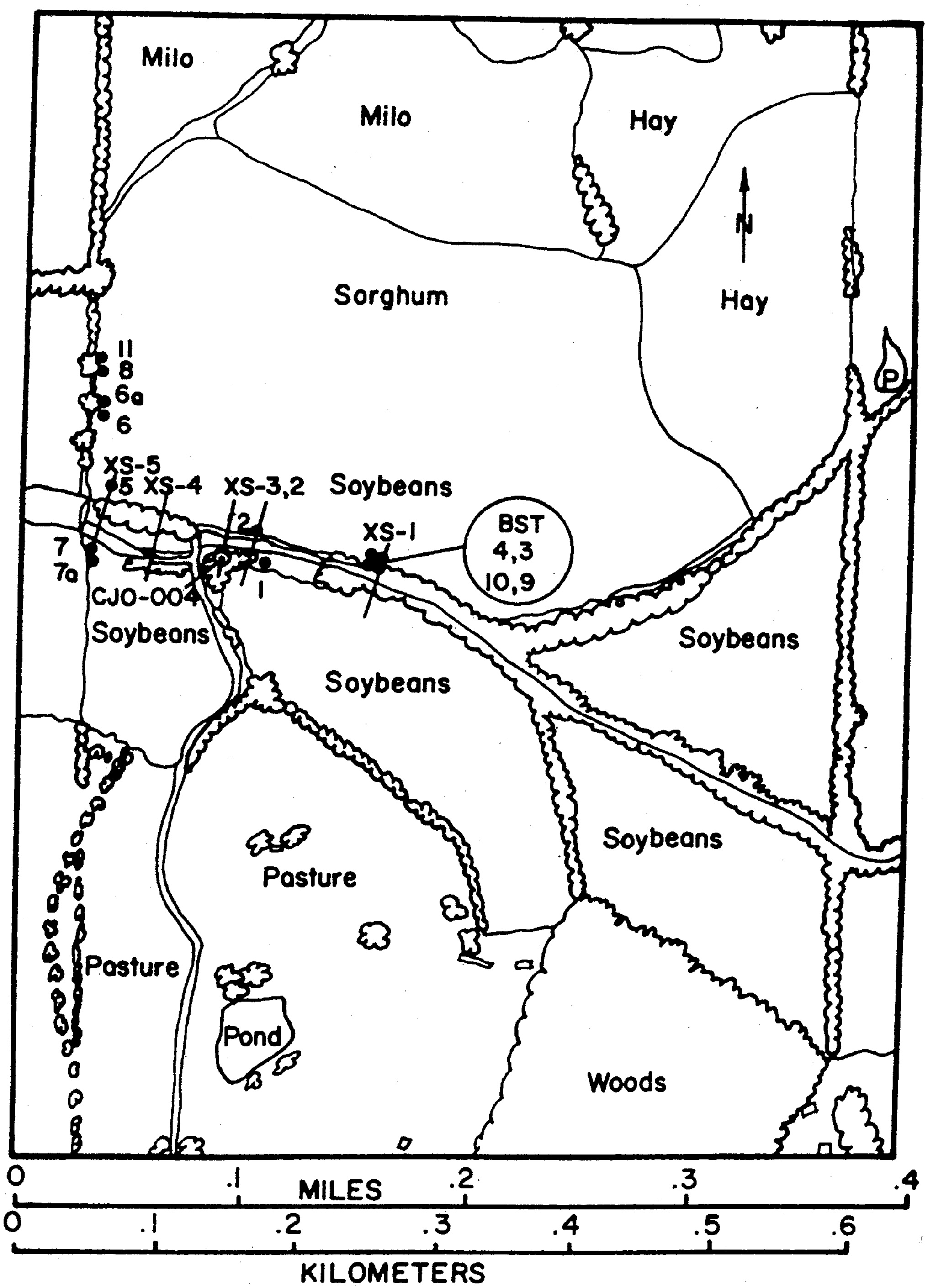


Figure 4.40 Locations of Woodruff Site Test Holes and Cross Sections

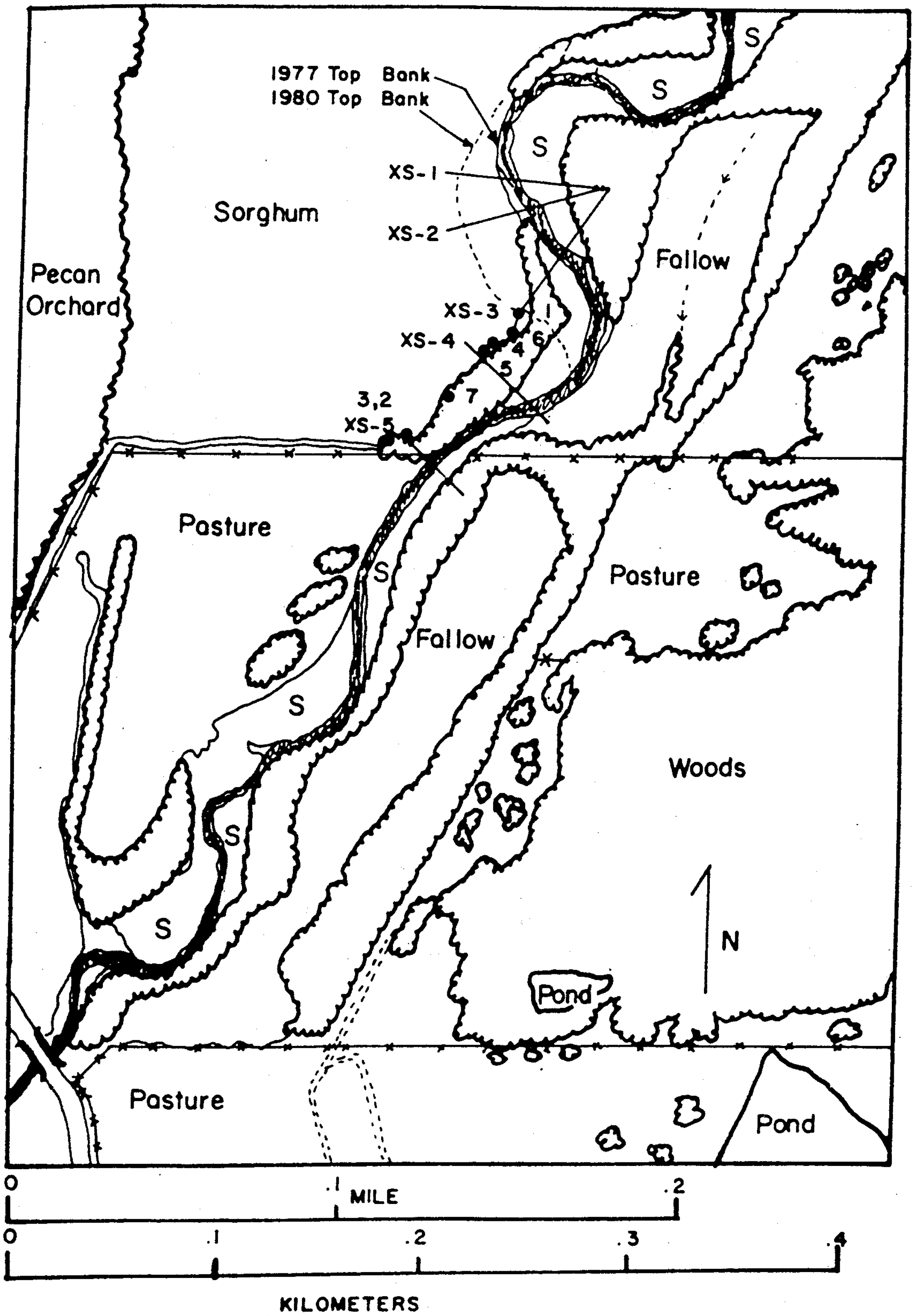


Figure 4.41 Locations of Leigh Site Test Holes and Cross Sections

Table 4.12 Soils Within Goodwin Creek Watershed (percent by Weight)

	Collins Silt		Grenada Silt		Loring Silt		Memphis Silt		Mixed Alluvial Silt	
Size Class	Disp. Soil	Eroded Sed.	Disp. Soil	Eroded Sed.	Disp. Soil	Eroded Sed.	Disp. Soil	Eroded Sed.	Disp. Soil	Eroded Sed.
> 1000	0.1	0.3	0.1	5.0	Trace	0.2	Trace	0.7	0.2	0.2
500 - 1000	0.2	1.0	0.6	8.8	0.1	0.9	0.1	6.4	2.2	2.1
250 - 500	0.3	2.2	2.0	10.1	0.5	2.5	0.2	13.0	20.4	30.6
125 - 250	0.5	2.8	2.6	5.8	0.5	2.7	0.3	6.9	25.5	24.3
63 - 125	0.5	1.8	1.3	5.0	0.4	1.7	0.4	3.0	6.7	4.4
31 - 63	22.1	27.1	21.8	15.3	21.6	21.5	18.6	20.8	12.2	7.8
16 - 31	45.5	40.7	40.3	27.7	36.5	32.8	34.3	28.1	18.8	16.9
8 - 16	21.4	16.2	13.5	12.4	16.8	19.5	14.1	10.6	7.8	6.2
4 - 8	4.3	1.0	3.1	3.7	6.0	5.1	5.4	3.7	1.3	1.1
< 4	6.5	6.9	14.7	6.2	17.6	13.1	26.6	6.8	4.9	6.4

Each Dispersed soil size distribution is based on triplicated analyses, and each sediment size distribution is the average of 4 to 6 runoff samples taken at a rain intensity of about 67 mm/h.

Table 4.13 Brief Description of Goodwin Creek Soils and their Estimated Physical Properties*

Soil Symbol	Slope Percent and Erosional Condition	Depth to seasonally high water table (feet)	Depth from surface (typical profile) (inches)	Classification (Unified)	Permeability (inches per hour)	Available Water Content (inches per inch of soil)	Reaction (pH value)	Dispersion	Shrink-Swell Potential
CaA CaB	0 - 2% 2 - 5%	1 - 2	0 - 6 6 - 11 11 - 16 16 - 50 50 - 60+	ML or CL ML or CL CL ML or CL ML or CL	0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 < 0.05 0.8 - 2.5	0.116 0.116 0.100 0.100 0.100	6.0 6.0 5.0 5.0 5.0	High Moderate Moderate Moderate High	Low High Moderate Low - Moderate Low
Cm Co	0 - 2% local alluvium, 0 - 3%	2 - 4	0 - 6 6 - 24 24 - 48+	ML or CL ML or CL ML or CL	0.8 - 2.5 0.8 - 2.5 0.8 - 2.5	0.125 0.116 0.116	5.5 5.5 5.0	High High High	Low Low Low
Fa Fl	0 - 2% local alluvium, 0 - 3%	0.5 - 2	0 - 7 7 - 43+	ML ML	0.8 - 2.5 0.8 - 2.5	0.125 0.125	5.0 5.0	High High	Low Low
GrA GrB GrB2 GrB3 GrC2 GrC3 GrD2 GrD3	0 - 2% 2 - 5% 2 - 5%, eroded 2 - 5%, severely eroded 5 - 8%, eroded 5 - 8%, severely eroded 8 - 12%, eroded 8 - 12%, severely eroded	2 - 10+	0 - 5 5 - 23 23 - 53+	ML CL ML or CL	0.8 - 2.5 0.8 - 2.5 <0.05	0.116 0.150 0.058	5.0 5.0 4.5	High Moderate Moderate	Low Moderate Moderate
Gs	gullied land, sandy	-----	-----	-----	-----	-----	-----	-----	-----
Gu	gullied land, silty	-----	-----	-----	-----	-----	-----	-----	-----

*Information taken from the USDA-NRCS Soil Survey, Panola County Mississippi (1963)

Table 4.13 Brief Description of Goodwin Creek Soils and their Estimated Physical Properties* -- continued

Soil Symbol	Slope Percent and Erosiona Condition	Depth to seasonally high water table (feet)	Depth from surface (typical profile) (inches)	Classification (Unified)	Permeability (inches per hour)	Available Water Content (inches per inch of soil)	Reaction (pH value)	Dispersion	Shrink-Swell Potential
LoB2 LoB3 LoC LoC2 LoC3 LoD LoD2 LoD3 LoE2 LoE3	2 - 5%, eroded 2 - 5%, severely eroded 5 - 8% 5 - 8%, eroded 5 - 8%, severely eroded 8 - 12% 8 - 12%, eroded 8 - 12%, severely eroded 12 - 17%, eroded 12 - 17%, severely eroded	5 - 20	0 - 5 5 - 33 33 - 54+	ML CL ML or CL	0.8 - 2.5 0.8 - 2.5 < 0.05	0.116 0.141 0.150	5.0 5.0 4.5	High Moderate High	Low Moderate Low - Moderate
MlF2 MlF3	17 - 35%, eroded 17 - 35%, severely eroded	10 -20	Memphis: 0 - 4 4 - 31 31 - 65 Loring: 0 - 5 5 - 33 33 - 54+	 ML CL ML ML CL ML or CL	 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 < 0.05	 0.116 0.141 0.150 0.116 0.141 0.150	 5.0 4.5 5.0 5.0 5.0 4.5	 High Moderate High High Moderate High	 Low Moderate Low Low Moderate Low - Moderate
MnF2	Memphis, Natchez, Guin, 17 - 40%, eroded	10 -20	Memphis: 0 - 6 6 - 25 25 - 49 49 - 60+ Natchez: 0 - 6 6 - 18 18 - 66+ Guin: 0 - 5 5 - 50+	 ML CL ML ML ML ML ML GM or SM GM or SM	 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 0.8 - 2.5 2.5 - 5.0 > 10.0	 0.116 0.116 0.150 0.150 0.116 0.116 0.150 0.058 0.058	 5.0 5.0 5.5 6.5 7.5 6.0 8.0 6.0 6.0	 High Moderate High High High High High High High	 Low Moderate Low Low Low - Moderate Low - Moderate Low - Moderate Low Low
Mx	Mixed Alluvial, 0 - 3%	1 - 3	-----	-----	-----	-----	-----	-----	-----

4.8.5 Topography

Topography of the watershed is provided by 15 and 7.5 minute USGS Quadrangle maps, USGS Digital Elevation Models (DEMs), a 1 to 5000 scale 2 to 5 foot contour-interval relief map and 1 to 500 scale detailed channel surveys prepared by the Corps of Engineers.

A DEM is a digital representation of a USGS 7.5 minute quadrangle map. It consists of a sampled array of elevations for ground positions that are at regularly spaced intervals (a grid) (U.S. GeoData, Digital Elevation Models, Data Users Guide). Ground positions in the grid are represented by the center of the pixel whose dimensions are 30 meters by 30 meters.

The information provides a good representation of the northing and easting coordinates, however, the vertical accuracy has been questionable. Evaluation of the data has shown disparities in the values of elevations between the DEMs and corresponding quadrangle maps. The elevations in the DEMs appear to be consistently higher in value and the errors greater than the levels of accuracy stated by the USGS. Also, streaking (horizontal scan lines), stitch lines (lines created by combining data sets from adjoining quads), depressions, and holes (missing data) have been found. Using various techniques of image processing, such as smoothing and filling, these problems have been largely overcome. Despite their limitations, the DEMs have been a convenient and useful resource enhancing the Goodwin Creek database. From the DEMs and ERDAS, digital maps of the elevation (Figure 4.42), slope (Figure 4.43), and aspect (Figure 4.44) have been created.

TOPAZ, a topographic analysis software program, is an automated procedure that evaluates topographic properties of large watersheds from a raster-type DEM. The primary application target for the model is the watershed parameterization for hydrologic surface runoff models. Parameterization includes the delineation of a drainage network and corresponding subcatchments, and the extraction of network, channel and subcatchment characteristics. The purpose of the model is to provide automated landscape evaluation measurements which are faster, more precise and reproducible than traditional manual techniques applied to topographic maps. The generated digital data can be readily exported to and analyzed by a GIS or computer model (Garbrecht and Martz, TOPAZ Model Documentation, 1994).

For Goodwin Creek, the output created by TOPAZ has been exported to both GRASS and ERDAS for processing. The data includes a watershed boundary (Figure 4.45), the contributing areas or subcatchments (Figure 4.46) and Strahler (stream ordered) drainage network (Figure 4.47).

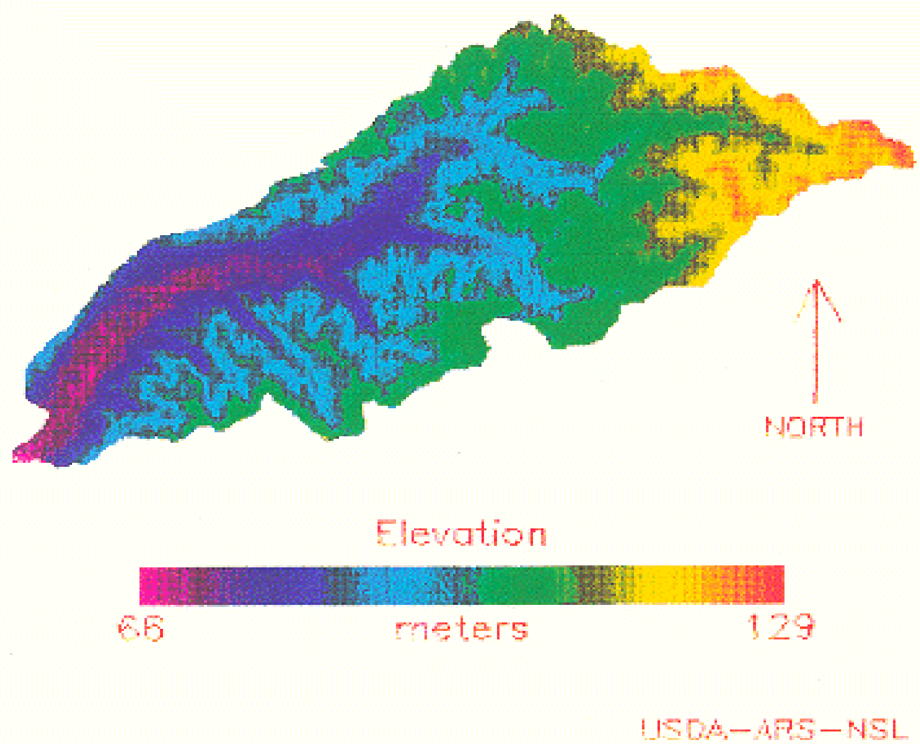


Figure 4.42 Digital Elevation Map of Goodwin Creek Watershed

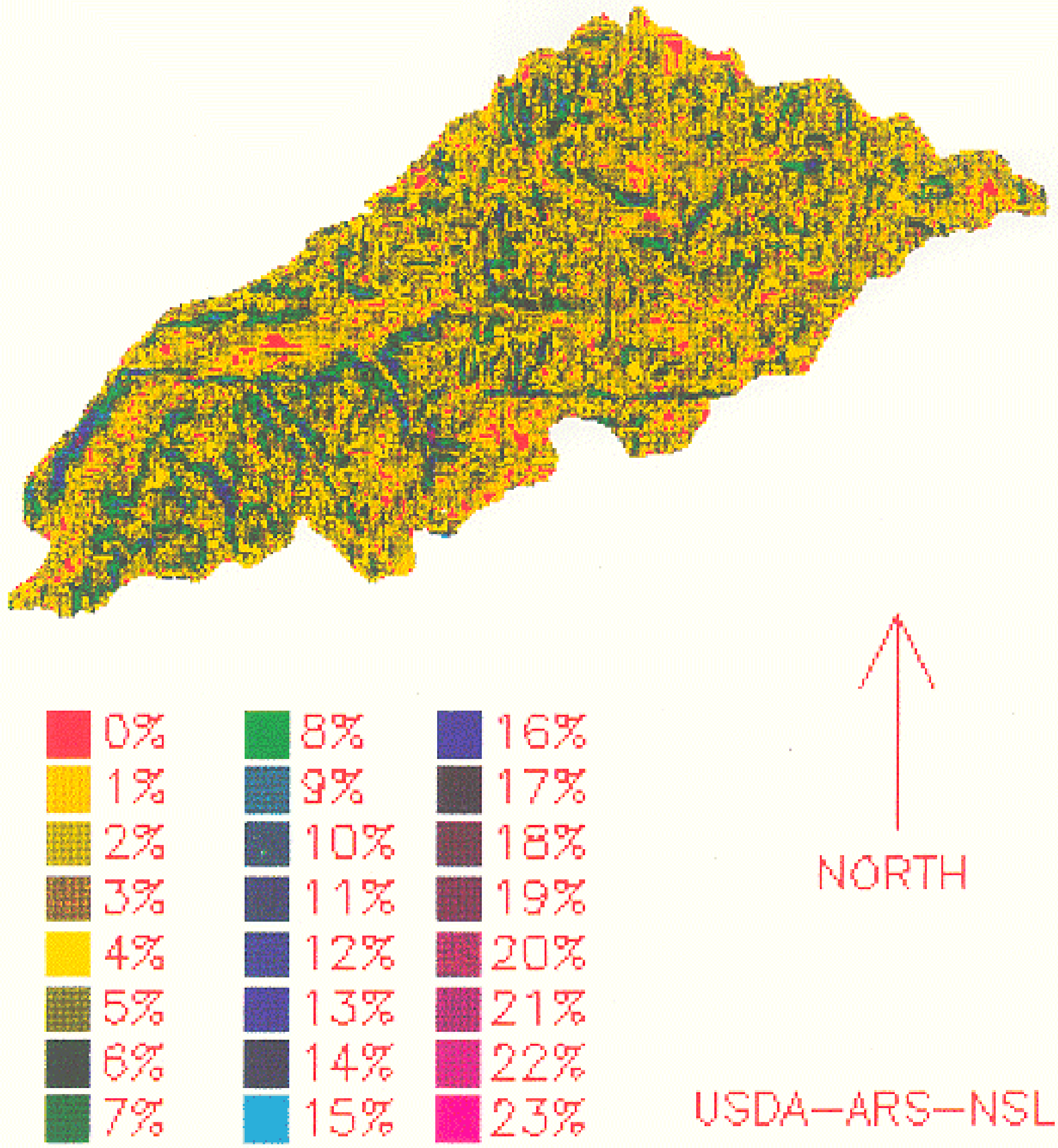


Figure 4.43 Digital Slope Map of Goodwin Creek Watershed

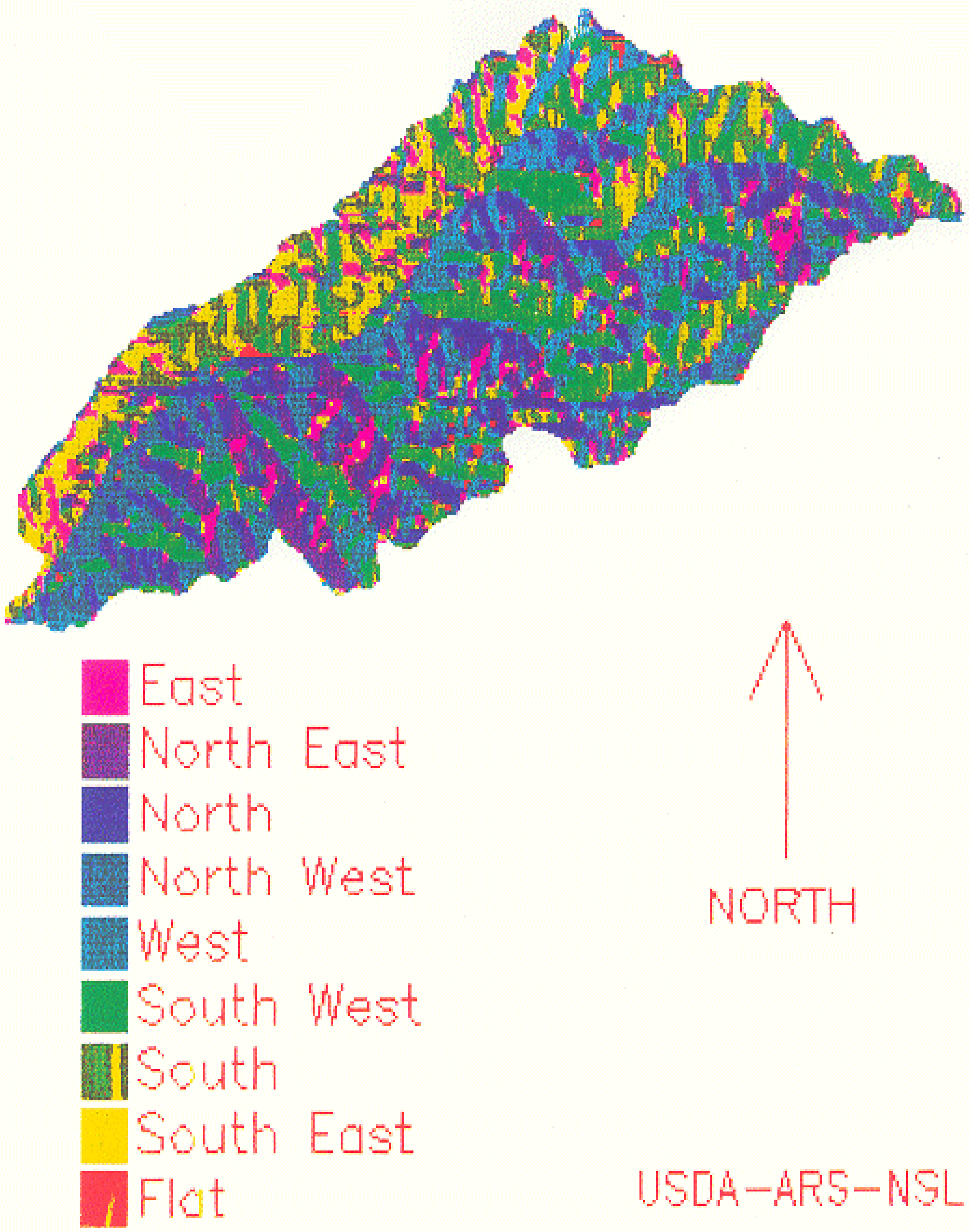


Figure 4.44 Digital Aspect Map of Goodwin Creek Watershed

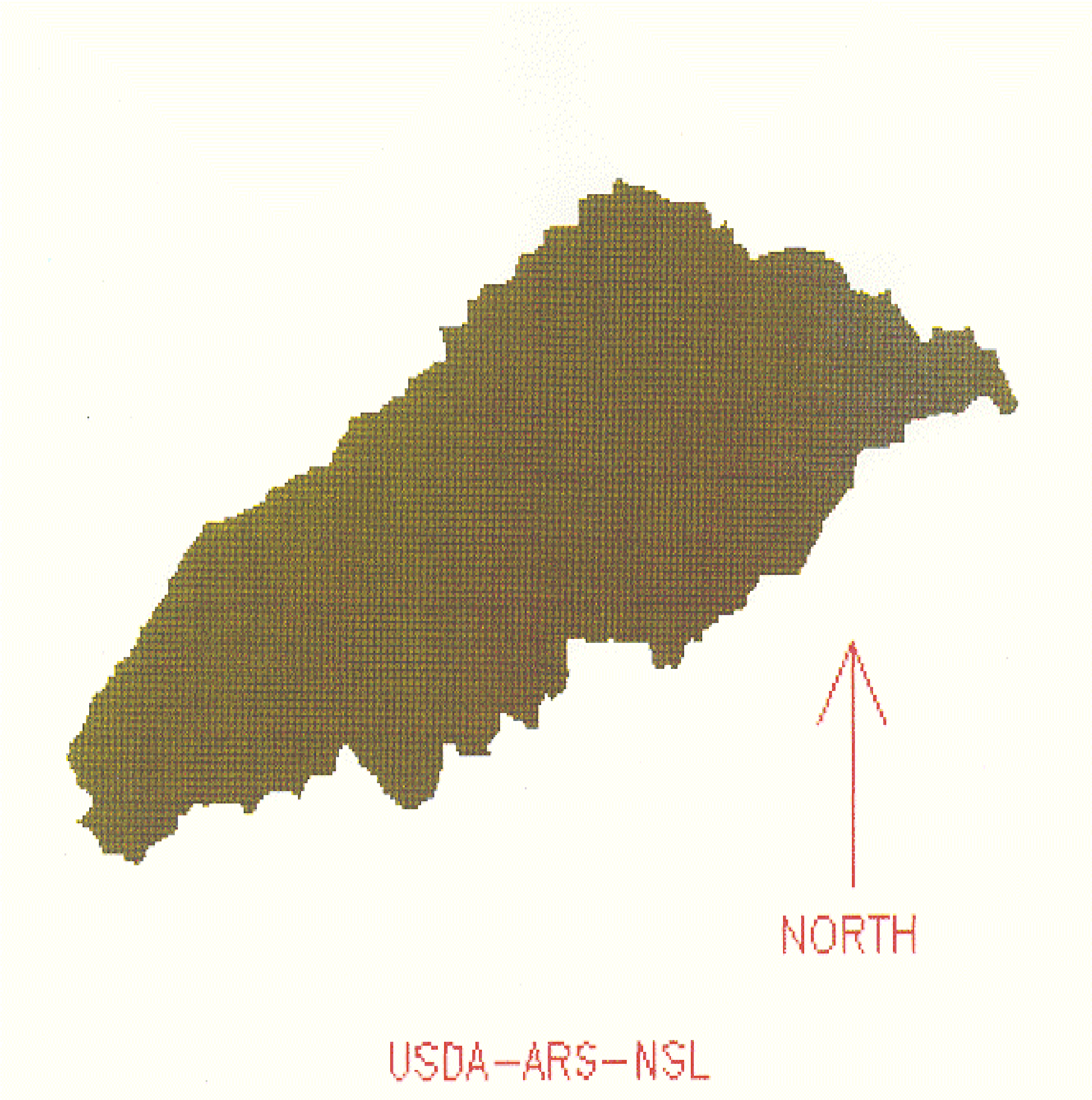


Figure 4.45 Watershed Boundary Map of Goodwin Creek
(created from DEMs by TOPAZ)

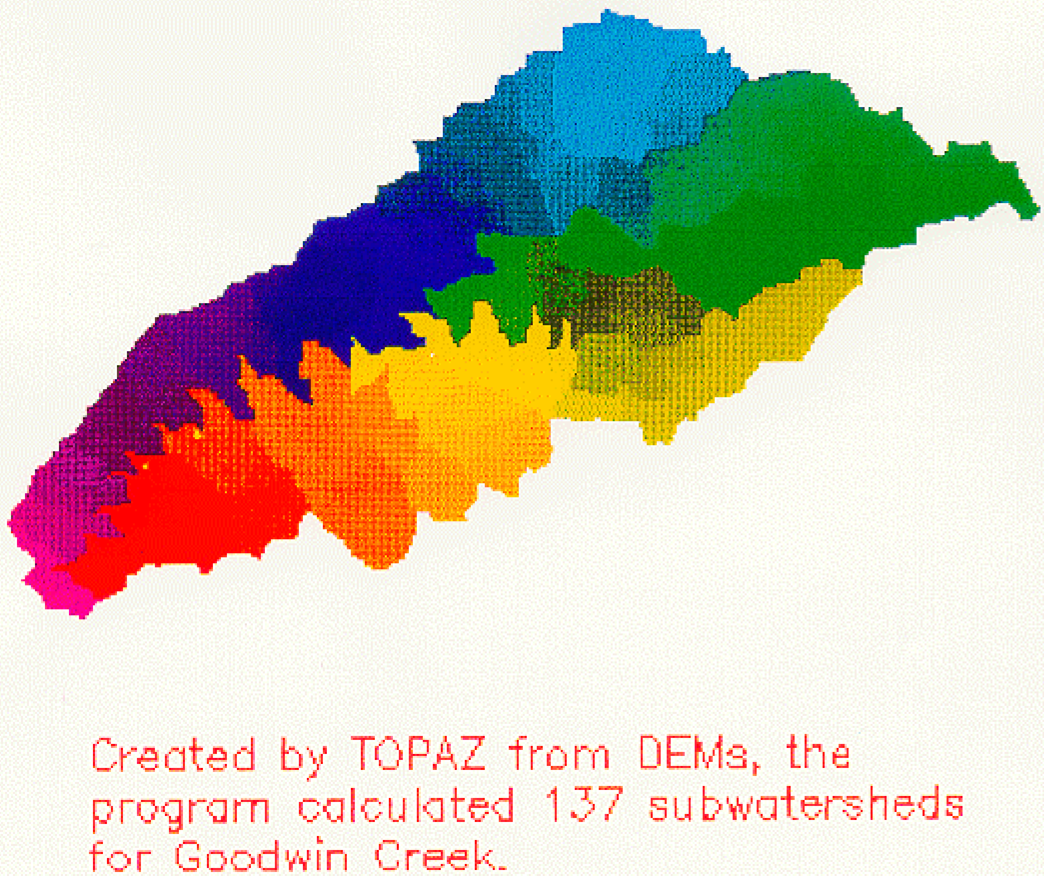


Figure 4.46 Subwatershed Map of Goodwin Creek Watershed
(created from DEMs by TOPAZ)

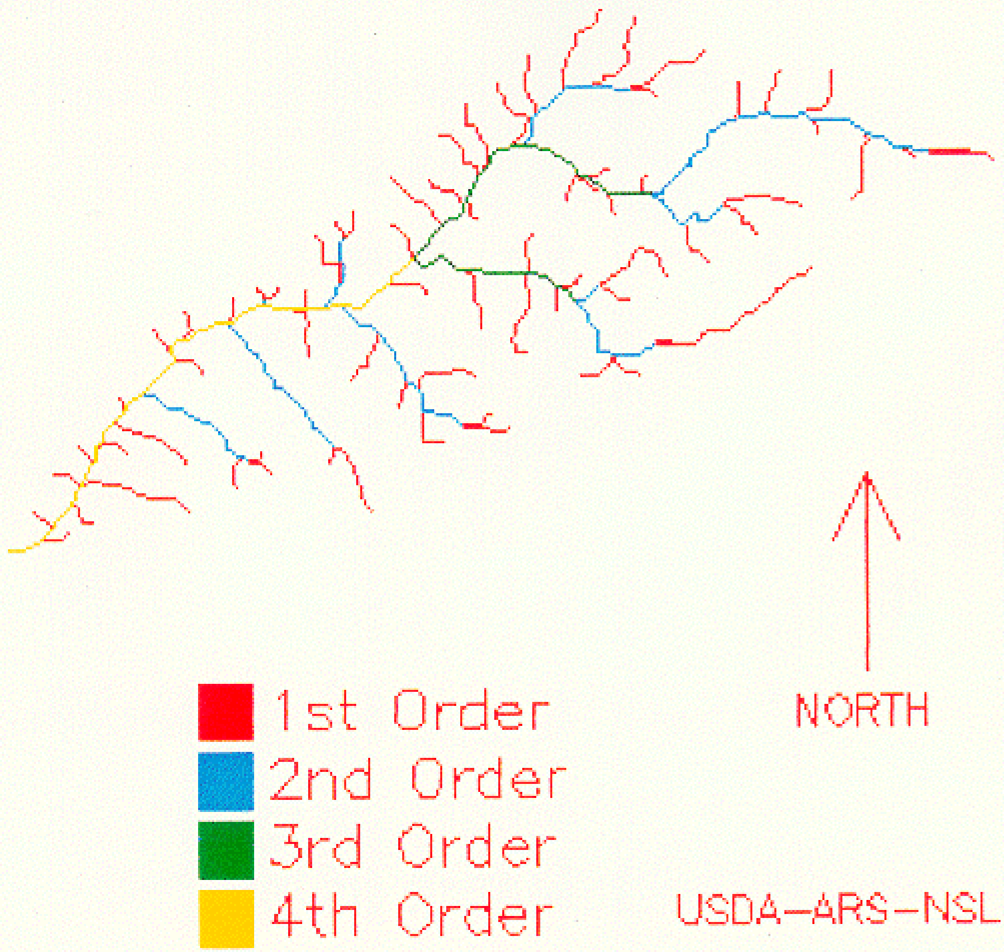


Figure 4.47 Strahler Drainage Network Map of Goodwin Creek Watershed
(created from DEMs by TOPAZ)

Chapter 5

Streamflow

5.1 Streamflow

The presentation of flow data is a statistical summarization of streamflow data for Goodwin Creek Watershed with eleven years of continuous record. The records were used in computing monthly and mean annual flows, high - low frequency and flow duration data.

For gaging station #1, the following information is provided: magnitude of monthly and annual flows, magnitude and frequency of annual low, high and instantaneous peak flows, and duration of daily mean flows. Additionally, information for the other thirteen gaging stations has been collected and is available upon request at the NSL.

The monthly and annual flow tabulations (Table 5.1) for the period of record include the maximum, minimum and mean monthly and mean annual flow, the standard deviation of the means, the coefficient of variation and the percentage of average annual runoff for each month.

5.1.1 Low Flow Frequency

The low-flow tabulations (Table 5.2) show the data necessary to plot standard low-flow frequency curves, which are based on the log-Pearson Type III frequency distribution. The tabulations show the annual minimum mean flows for periods of 1, 3, 7, 10, 30, 60, 90, 183, and 365 consecutive days for recurrence intervals for 2, 5, 10, 20, 50, and 100 years. The annual nonexceedance probabilities are 50, 20, 10, 5, 2, and 1 percent, respectively. The annual minimum mean flows are based on the water year. Recurrence intervals for low flows represent the average length of time between occurrences of annual minimum mean flows that are less than the stated flow magnitude. Expressed as a percentage, the nonexceedance probability is the probability or chance that the annual minimum mean flow will be less than the stated magnitude in any given year. Recurrence intervals generally were reported only to twice the period of record.

Table 5.1 Summary of Monthly and Annual Discharge for Station 1, Based on Water Years 1982-1993

Month	Maximum (cfs)	Minimum (cfs)	Mean (cfs)	Standard Deviation (cfs)	Coefficient of Variation	Percent of Annual Runoff
October	354.00	0.20	5.79	9.19	0.63	3.6%
November	568.31	0.25	10.39	8.67	1.20	6.4%
December	926.21	0.37	25.72	25.84	1.00	16.0%
January	484.61	0.33	12.89	11.80	1.09	8.0%
February	1136.50	0.33	29.74	27.33	1.09	18.5%
March	573.22	0.37	17.56	11.41	1.54	10.9%
April	905.70	0.37	22.69	26.43	0.86	14.1%
May	763.82	0.30	16.59	18.72	0.89	10.3%
June	221.05	0.25	7.29	7.93	0.92	4.5%
July	506.21	0.25	5.78	9.01	0.64	3.6%
August	225.42	0.19	3.88	3.86	1.00	2.4%
September	439.09	0.15	2.72	4.16	0.65	1.7%
Annual	592.01	0.28	13.42	13.70	0.96	100.0%

Table 5.2 Magnitude and Frequency of Annual
Low Flow for Station #1, Based on Water Years 1982-1993

	Discharge, in cfs, for indicated recurrence interval, in years, and nonexceedance probability, in percent					
Period (consecutive days)	2 50%	5 20%	10 10%	20 5%	50 2%	100 1%
1	0.54	0.27	0.18	0.12	0.08	0.06
2	0.55	0.28	0.18	0.13	0.08	0.06
3	0.56	0.28	0.19	0.13	0.08	0.06
7	0.61	0.32	0.22	0.15	0.10	0.07
10	0.64	0.33	0.22	0.16	0.10	0.08
30	0.79	0.47	0.34	0.26	0.18	0.14
60	1.18	0.63	0.45	0.33	0.23	0.19
90	1.80	0.89	0.62	0.46	0.33	0.26
183	7.02	3.28	2.13	1.46	0.94	0.69
365	12.13	7.18	5.29	4.05	2.94	2.35

5.1.2 High Flow Frequency

The high flow frequency tabulations (Table 5.3) show the data necessary to plot standard high-flow frequency curves, which are based on the log-Pearson Type III frequency distribution. The tabulations show the annual maximum mean flows for periods of 1, 3, 7, 10, 30, 60, 90, 183, and 365 consecutive days for recurrence intervals of 2, 5, 10, 20, 50, and 100 years. The associated annual exceedance probabilities are 50, 20, 10, 5, 2, and 1 percent, respectively. Recurrence intervals for high flows represent the average length of time between occurrences of annual maximum mean flows equal to or greater than the stated flow magnitude. Expressed as a percentage, the exceedance probability is the probability or chance that the annual maximum mean flow will equal or exceed the stated magnitude in any given year.

Table 5.3 Magnitude and Frequency of Annual High Flow for Station #1, Based on Water Years 1982-1993

	Discharge, in cfs, for indicated recurrence interval, in years, and exceedance probability, in percent					
Period (consecutive days)	2 50%	5 20%	10 10%	20 5%	50 2%	100 1%
1	505.51	814.76	1044.91	1361.66	1615.18	1882.93
2	326.98	568.91	754.50	1014.11	1223.99	1446.82
3	247.76	434.86	573.53	760.67	906.63	1056.87
7	130.05	214.74	278.41	366.55	437.39	512.38
10	96.73	159.14	205.24	268.04	317.74	369.68
30	48.69	75.75	95.22	121.33	141.77	162.98
60	32.81	53.53	68.64	88.98	104.91	121.42
90	25.99	43.81	57.75	77.72	94.28	112.27
183	20.05	32.87	41.68	52.89	61.18	69.37
365	12.13	19.08	23.52	28.83	32.53	36.02

5.1.3 Flood Frequency

Shown as instantaneous peak flow, the flood-frequency tabulations (Table 5.4) show the data necessary to plot standard flood-frequency curves, which are based on a log-Pearson Type III frequency distribution. These data are magnitudes of instantaneous peak flows at selected recurrence intervals (annual exceedance probabilities). The flood-frequency tabulations list the magnitudes of annual instantaneous peak flows for recurrence intervals of 2, 5, 10, 20, 50, and 100 years. The associated annual exceedance probabilities are 50, 20, 10, 5, 2, and 1 percent, respectively. Additionally, the exceedance of daily peak flows obtained at measuring station 1, for the calendar years 1982-1991 are shown in Figure 5.1.

Table 5.4 Magnitude and Frequency of Instantaneous Peak Flow for Station #1, Based on Period of Record 1982-1993

Discharge, in cfs, for indicated recurrence interval, in years, and exceedance probability, in percent					
2 50%	5 20%	10 10%	20 5%	50 2%	100 1%
2761.3	4054.1	4908.3	5975.9	6760.1	7533.8

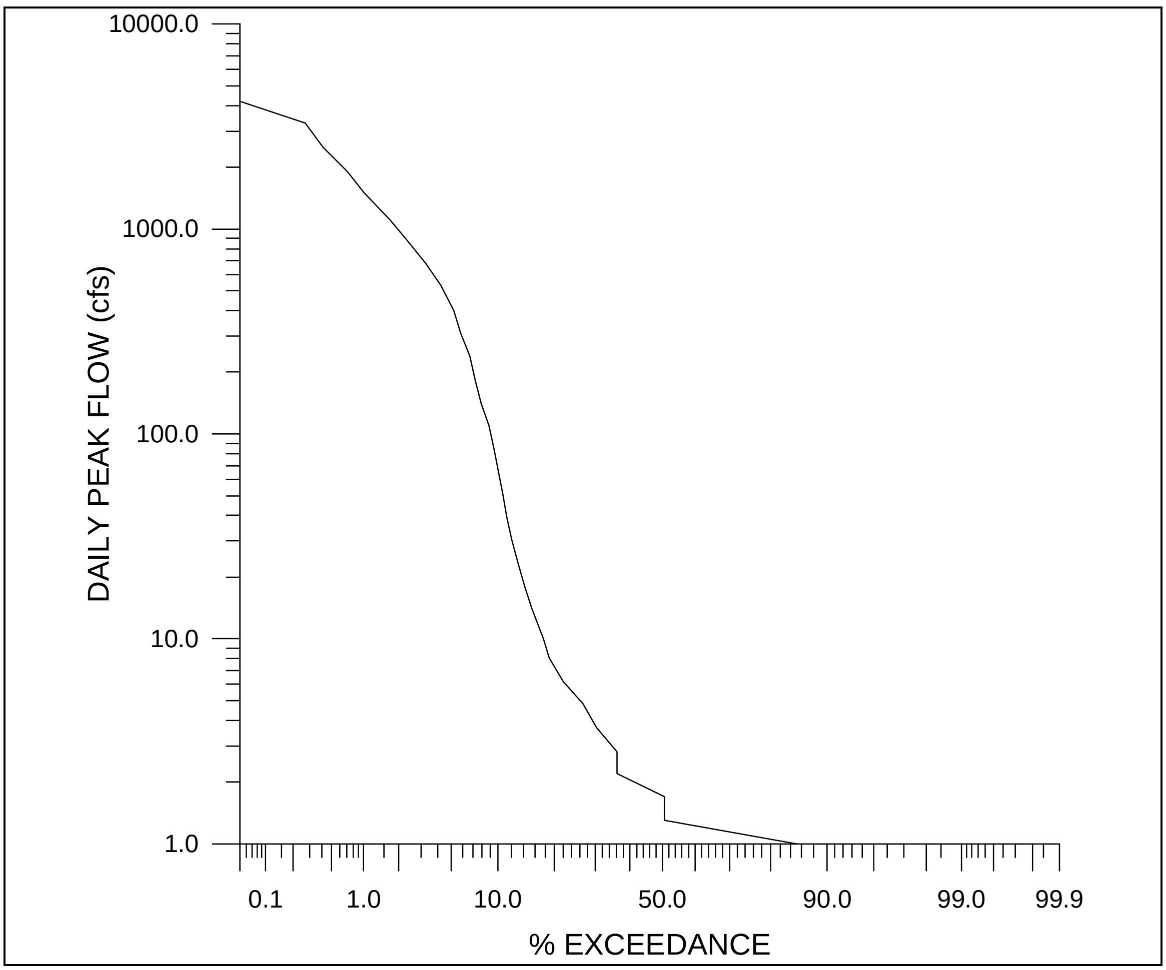


Figure 5.1 Goodwin Creek Watershed % Exceedance of Measured

5.1.4 Flow Duration

The flow-duration tabulations (Table 5.5) show the data necessary to plot a standard flow-duration curve, which is a cumulative frequency curve that shows the percentage of time that specified daily flows were equaled or exceeded during the period of record. The tabulations show the flows that were equaled or exceeded for a given percentage of time.

The mean discharge from 1982-1993 on Goodwin Creek is highest during February and lowest during September (Figure5.2). Baseflow follows a similar trend as mean discharge, while the maximum discharge does not have a well defined trend. These discharges follow the trend produced by high rainfall during the months of December through May and lower rainfall during the other months.

Storm events on Goodwin Creek Watershed produce runoff that swiftly exits the watershed. Discharge quickly returns to pre-storm baseflow levels within one to three days. This quickness that the flow exits the watershed can be illustrated with Figure 5.3. For measuring station #1, during the month of April, 1982, there were several typical spring storms recorded. These storms produced hydrographs with one or more peaks and of a short duration. The storm of April 2 through April 4, 1982 is expanded in Figure 5.4. The majority of flow occurred within 24 hours, with two distinct peaks.

Table 5.5 Duration Table of Daily Mean Flow for Station #1, Water Years 1982-1993

Discharge, in cfs, which was exceeded for indicated percentage of time						
1.0%	4.4%	9.7%	14.5%	19.3%	24.7%	32.1%
270.0	66.0	16.0	8.0	5.6	4.0	2.8
40.3%	56.6%	83.8%	87.5%	95.4%	98.9%	99.9%
2.0	1.4	0.7	0.5	0.3	0.2	0.2

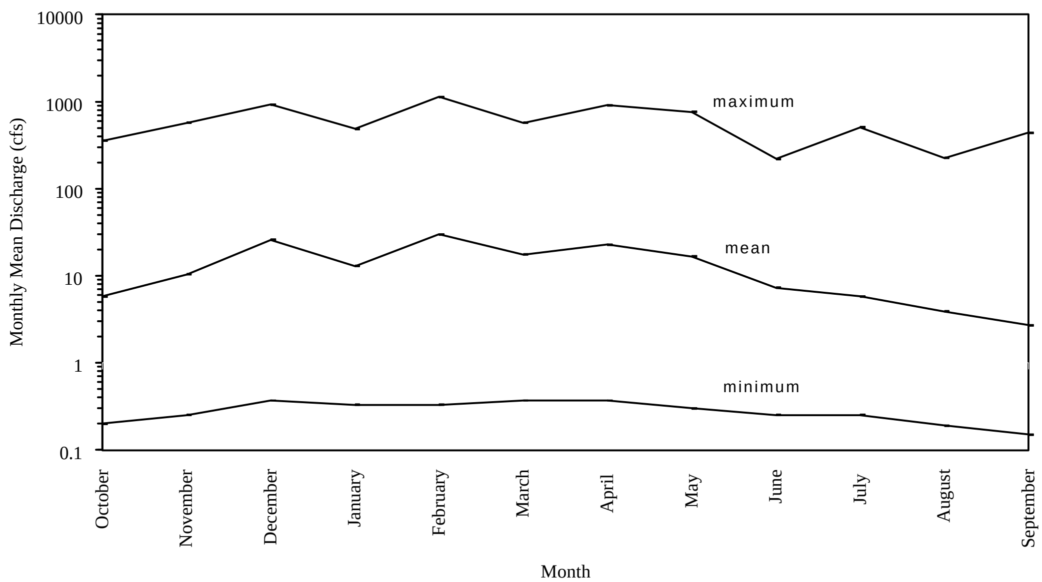


Figure 5.2 Monthly Maximum, Mean and Minimum Discharge for Goodwin Creek, 1982 to 1993

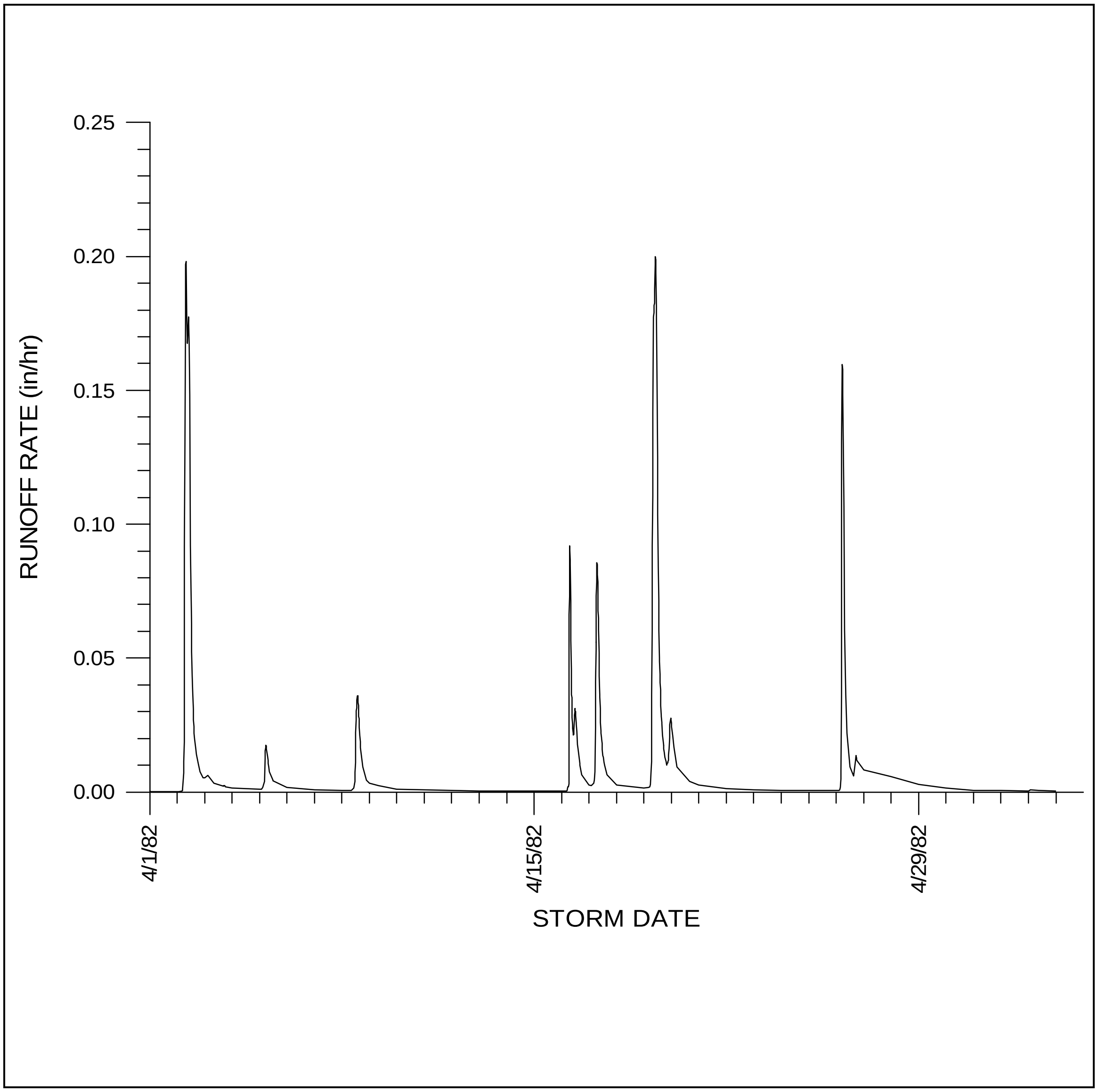


Figure 5.3 Goodwin Creek Watershed Measured Runoff Rate
At Measuring Station 2 for the Month of April, 1982

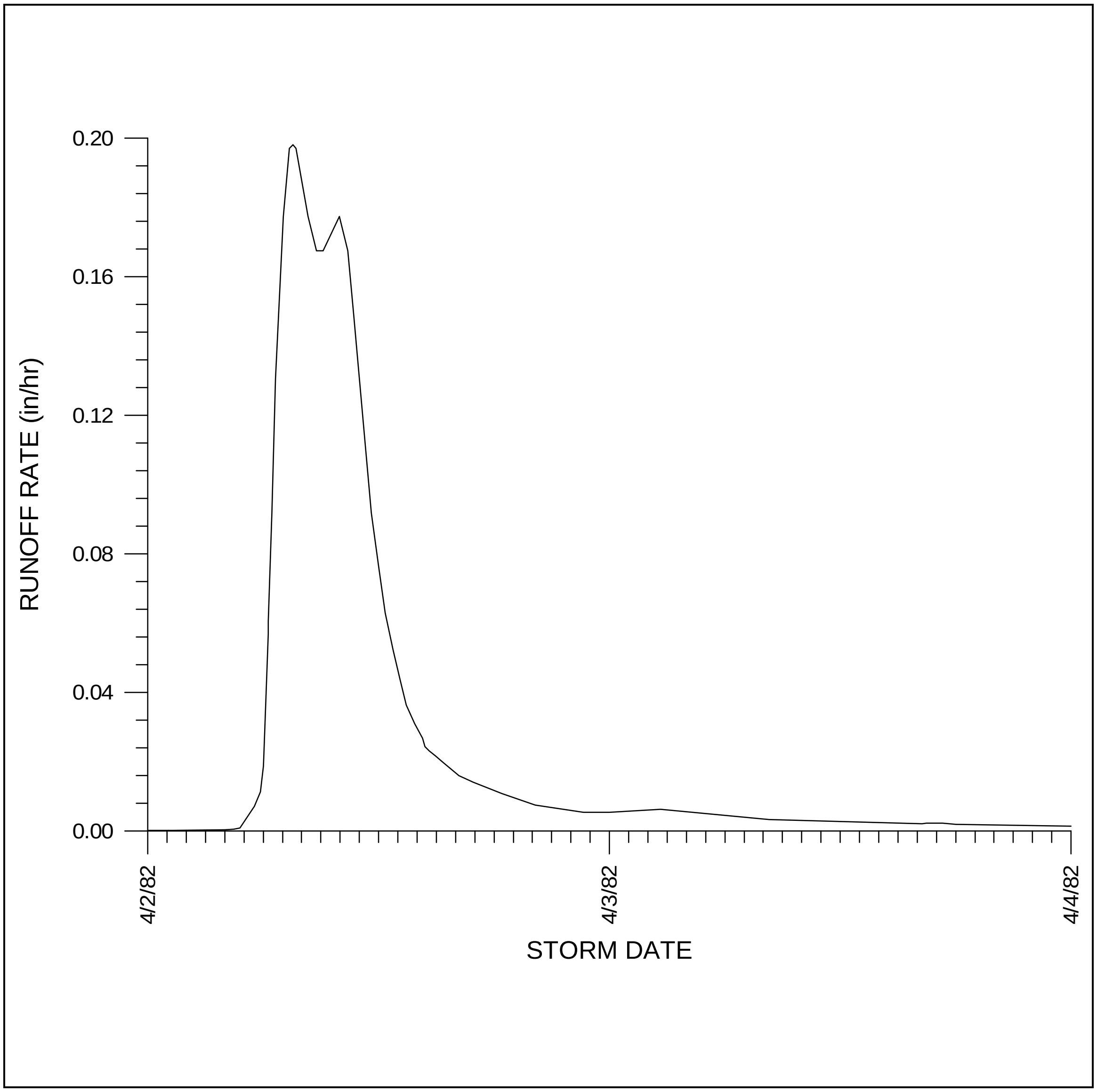


Figure 5.4 Goodwin Creek Watershed Measured Runoff Rate
At Measuring Station 1 for April 2-4, 1982

Chapter 6

Sediment Yield

6.1 Sediment Transport

The sediment transport rate is a highly variable quantity, changing not only with the flow but also spatially across and along the channel as areas of erosion (such as on dune backs) increase the transport rate and areas of deposition (on the downstream slope of dunes) decrease the transport rate. It varies temporally with the passage of flood events and the migration of the bed configurations (DeCoursey,1981).

Not only do bed forms impart temporal and spatial variability to the sediment transport rate, but they are also one of the features used by a stream to maintain some semblance of equilibrium when relatively wide deviations in the amounts of water and sediment are delivered to a reach over short time periods. When the sediment concentration supplied to a stream is relatively low, ripples and dunes which form on the stream bed offer high flow resistance, increase the flow depth while reducing the flow velocity, and thereby reduce the transport capacity of the flow. Conversely, when flow rates are high, and the potential to carry sediment is also high, the rough bed forms are obliterated leaving a bed that is relatively smooth (hydraulically) and characteristic of the transition and antidune regimes. This relatively smooth bed permits a higher flow velocity and shallower depth than would be permitted by a rougher bed and gives a higher transport capacity (DeCoursey,1981).

Since a lot of sediment motion may be involved in bed form changes, a hysteresis effect may be induced in the transport rate. Bed form adjustment will lag the imposed changes so that instantaneous conditions are likely different from those of equilibrium flow and transport. In view of these complexities and short term deviations, the reach can be said to approximate some average relationship between the quantities of water and sediment passing through the channel (DeCoursey,1981).

The goal of most transport relationships is to predict the equilibrium transport rate in terms of the conditions of the imposed flow. Few investigators have dealt with unsteady flow conditions, therefore until hysteresis lags, unsteady flows, and spatial and temporal variations are adequately investigated; expectations for a reliable, instantaneous sediment transport rate prediction are nil (DeCoursey,1981).

Numerous equations and procedures have been proposed in the literature for estimating the sediment transport rate. ASCE Task Committee (1971) and Shulits and Hill (1968) are two excellent review articles that treat several of the equations in detail; so only a brief discussion of them will be given here. The procedures vary in complexity from relationships between the sediment transport rate and only on flow parameter such as shear stress, mean velocity, or stream power; to basic variable correlations (Colby,1964); and to extremely complex procedures which include state-of-the-art of transport mechanics and alluvial channel hydraulics typified, by the Einstein Bed-Load Function (Einstein,1950). Both articles show great disparity between sediment rating curves calculated for the same stream reaches by the different procedures (DeCoursey,1981).

It should be noted that no matter how complex a calculation procedure may be, the theory becomes inadequate at some point and experimental data must be used to complete the procedure. Thus, the calculation is no better than the data upon which it is based. Furthermore, the data comes from flow-transport systems with different degrees of variability as mentioned previously. Also, the complexity of design criteria offers little advantage except for a better understanding of transport processes (DeCoursey,1981).

The basic variable correlation of Colby (1964) seems to do as well if not better than other methods in estimating the transport rate. This method presents the sediment transport rate as a function of depth, velocity, and particle size in a graphical correlation. A generalization of this method is obtained by normalization of the equations of motion for a sediment-water mixture (Willis and Coleman,1969). The procedure presents the density corrected sediment concentration of the available flume data as a function of Froude number, $V / gy^{1/2}$, in which V is the velocity, g is the acceleration of gravity and y is flow depth, and a grain diameter similitude number, $g^{1/3}\ d_{50} / v^{2/3}$, in which g is the acceleration of gravity, d_{50} is the median particle grain size, and v is the kinematic viscosity (DeCoursey,1981).

Although the basic variable or similitude correlations may serve as good design tools, they give little insight into the actual mechanisms of sediment transport. The sediment transport rate is generally divided into two parts - that which moves in almost continuous contact with the bed and that which moves in suspension in the body of the flow. The suspension mechanism is the occurrence of turbulent eddies that interchange sediment between adjacent levels in the flow. A balance between the upward diffusion by turbulence and the downward settling by gravity defines the equilibrium concentration distribution for an assumed distribution of turbulent diffusivity (Vanoni,1946). Several different models for the turbulent diffusivity have been proposed; all give comparable results in the central flow region (DeCoursey,1981).

Near the bed the suspension theory breaks down and some other means must be used to account for the transport in the near bed region. Calculations made according to models based on present suspension theory give only the concentration distribution over the flow depth relative to the concentration at some arbitrary reference point. Some other independent means must be used to specify the value of this reference concentration (DeCoursey,1981).

The bed-load part of the sediment transport rate is often poorly defined and always difficult to measure. The bed load may be restricted to that part of the sediment load moving in continuous contact with the bed or it may be considered to be all the load moving below some arbitrary level in the flow. The near-bed transport processes are generally agreed to be strongly coupled to the shear stress on the bed or the rate that the stream expends energy per unit of bed area (stream power). The relationships for bed-load are experimental correlations that include shear stress or stream power (DeCoursey,1981).

Potential methods for estimating the equilibrium transport rate may be summarized as either the gross variable methods or the transport mechanics methods. Gross variable methods use graphical or mathematical correlations between the independent variables (mean flow and sediment features), and the dependent variable (transport rate or mean sediment concentration). The transport mechanics approach is more complex but in general begins with a determination of the bed load from a gross variable correlation. The bed load along with assumptions for the concentration at the top of the bed layer then gives the lower concentration limit for suspension calculations. The product of local values, of concentration and velocity, from assumed distribution models is then integrated over the flow depth to determine the suspended load. The sum of bed load and suspended load then gives the total load (DeCoursey,1981).

In either method, the sediment load estimates are only as good as the data, and assumptions upon which the methods are based. Because of the difficulties of obtaining reliable field data, emphasis is placed on data from laboratory flumes. Since the flows in laboratory flumes are generally small, additional data for equilibrium flows in larger flow systems are needed to test the validity of transport concepts (DeCoursey,1981).

The concepts of sediment transport discussed above assume that the hydraulics of the flow system are already defined, when in fact these may be completely unknown. About half of the complex calculations of the Einstein Bed-Load Function deal with flow hydraulics; the remainder deal with transport relationships. The following section addresses the resistance relationships that provide the dependent hydraulic variables of the transport relationships (DeCoursey,1981).

6.1.2 Sediment Transport Samples

The sediment in transport in the channels of Goodwin Creek can be separated into three groups based on the problems associated with collecting representative samples for each group: fines (<0.062 mm), sand (0.062 - 2.0 mm), and gravel (> 2.0 mm). A summary of the sampling technique used for each size distribution, number and type of samples collected and years in which samples were collected is contained.

6.1.3 Fine Samples

Fine sediment load samples (< 0.062mm) are collected using the automatic pumping samplers (Table 6.1) with intake slot widths of 3.2 mm from fixed heights within each flume of 0.15 or 0.30 m above the center of the 'V' shaped floor (see Appendix A for location). These samples collected from the pumping samplers are reliable for fines (Fig. 6.1), but are determined to be unreliable for sands due to the spatial and temporal variability of sand movement across and through the channel cross section. A power function has been used to relate depth in the structure to mean concentration of the fines:

$$(1) \quad C_f = KDH^E$$

where C_f is the concentration of the fines (ppm), K is a shift factor, D and E are regression coefficients, and H is the depth of flow (ft.) in the supercritical flow structure (Willis et al.,1986). Equation (1) has been used to calculate fine sediment loads using the depth of flow in the structure and a shift factor calculated if pump samples are available (Table 6.3). When samples are not available, equation (1) is used with K=1.

6.1.4 Sand Samples

Due to the spatial and temporal variability of sand movement, manual depth integrated samples have been collected and used to determine sand loads. During the first few years of watershed operation, samples were collected using the US P-63 cable mounted sampler, however, this left the lowest 0.1 m of the flow depth unsampled. Later, samples were collected using DH-48 samplers through the flow nape at the downstream end of the structures. Using this technique, the entire depth of flow was sampled at equal-transit-rates (ETR). These total sand load (TSL) samples that have been collected at 11 stations (Table 6.2). In most cases, TSL samples have been collected at several verticals across the cross-section over a short time period to account for lateral variations in the transport of sand. Presently, sand loads have been calculated only for stations 1 and 2 in the watershed. Equations (2) and (3) were used by Willis (1991) to calculate sand loads for the time period of 1985-1988:

$$(2) \quad C_S = 52.4\, e^{0.675H} \;;\quad H > 1.22 \text{ ft.}$$

$$(3) \quad C_S = 97.6\, H \;;\; H \leq 1.22 \text{ ft.}$$

where C_S is the concentration of sand (ppm by weight). Willis (1991) calculated sand loads for the water years 1985-1988 using an equation with a shift factor similar to equation (1), as well as just using the mean curves (equations 2 and 3). The yearly calculated sand loads for the four years were always greater using the equation with the shift factor. The sand loads calculated by the two methods were factors of 2 and 3 apart for two of the four years. These differences have not been explained, although the mean curves used (equations 2 and 3) have been independently calculated and verified. Until the discrepancy between the sediment loads calculated by the two techniques is explained, it is recommended that the mean curve be used for calculations of sand loads.

Preliminary analysis of the TSL data showed that only stations 1, 2, 3, 5 and 13 have large enough numbers of samples collected over a sufficiently wide range of flow depths to construct mean sand concentration versus flume depth relations (Table 6.3).

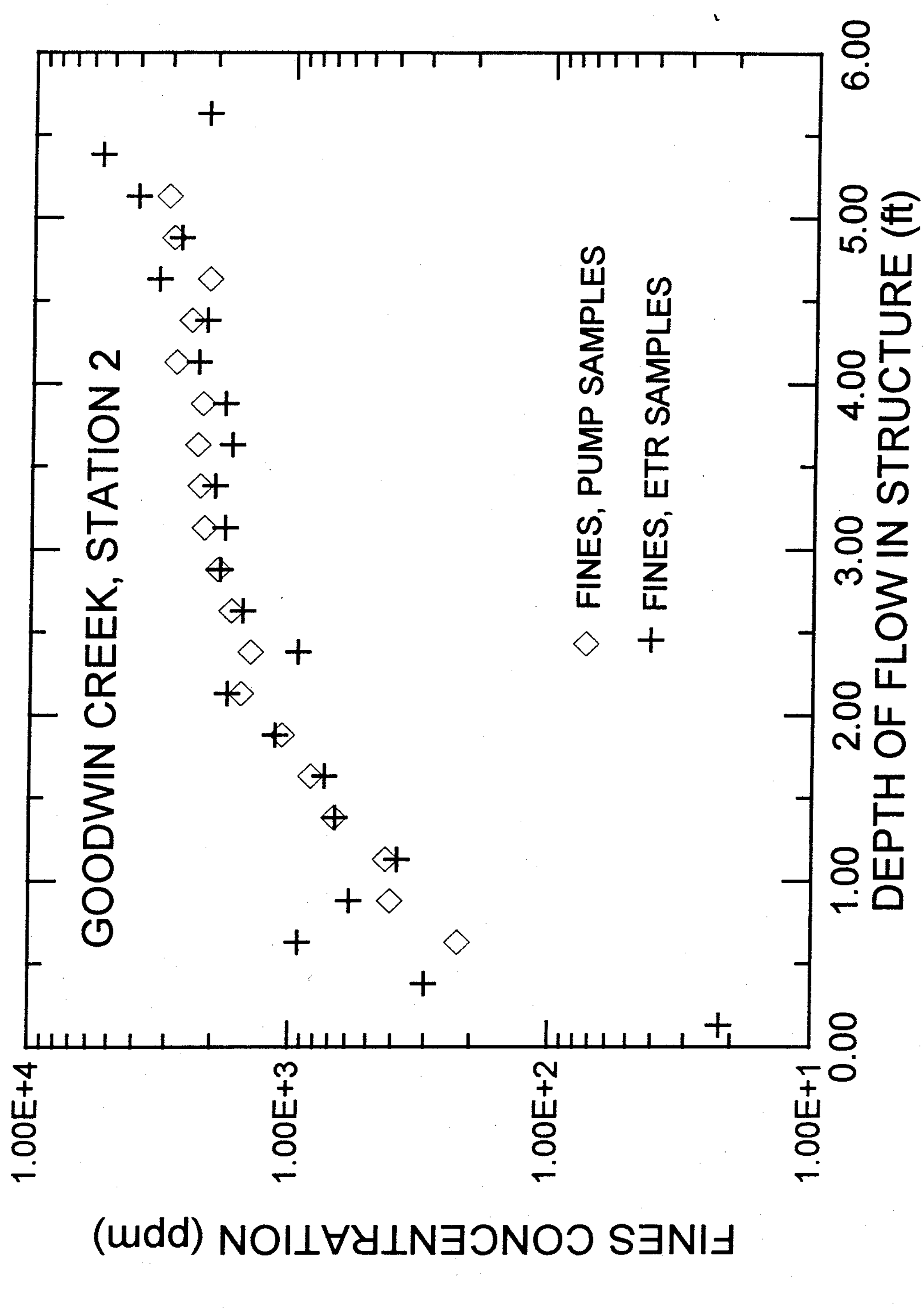


Figure 6.1 Pumping Samples vs. DH-48 Samples for Fine Sediment Loads of Goodwin Creek

Table 6.1 Number of Samples* per Station for Fine Sediment (< 0.062 mm), 1978 to 1994

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1978	0	16	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	0	72	0	0	0	0	0	0	0	0	0	0	0	0
1981	138	243	82	46	138	21	33	33	6	48	0	0	22	0
1982	641	679	260	334	590	470	512	477	317	380	306	463	632	362
1983	387	446	369	575	554	356	560	306	190	313	201	310	471	513
1984	584	659	446	679	454	355	580	279	303	250	190	489	349	455
1985	350	336	383	431	325	276	463	226	247	188	132	308	186	282
1986	402	400	226	335	357	285	381	159	143	163	172	370	239	162
1987	136	114	86	148	231	138	166	35	80	96	47	148	126	133
1988	160	135	128	208	135	162	145	85	48	77	37	76	139	158
1989	172	111	192	224	144	136	87	108	6	94	78	104	184	157
1990	256	0	0	0	143	16	0	75	0	73	144	135	246	200
1991	177	49	78	65	285	44	0	178	16	82	72	37	112	169
1992	87	166	117	221	144	160	136	104	66	71	96	158	149	118
1993	72	121	117	202	135	78	182	63	24	7	41	86	142	53
1994	66	95	40	14	74	34	68	82	-------	9	-------	68	25	29

* Samples collected using the Automatic Pump Sampler

Table 6.2 Number of Samples* per Station for Total Sand Load (0.062 – 2.0 mm), 1978 to 1994

Station # / Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1978	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1979	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1980	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	136	0	0	0	0	0	0	0	400	0
1983	0	0	1	0	412	0	0	0	0	0	0	0	241	0
1984	17	451	22	118	29	36	151	0	18	0	0	16	178	0
1985	366	697	28	39	2	12	141	0	41	0	0	37	9	13
1986	290	935	97	3	6	0	46	0	0	0	0	0	145	37
1987	86	193	0	0	0	0	0	0	0	0	0	0	4	0
1988	23	47	0	0	0	0	0	0	0	0	0	0	0	0
1989	0	18	9	0	0	0	0	0	0	0	0	0	0	0
1990	274	0	594	0	0	0	0	0	0	0	0	0	77	0
1991	690	0	0	0	0	0	0	0	0	0	0	0	0	0
1992	142	3	0	0	0	0	0	0	0	0	0	0	0	0
1993	246	0	0	0	0	0	0	0	0	0	0	0	0	0
1994	0	83	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

* Samples collected using the DH-48 Sediment Sampler

Table 6.3 Number of Bulk Sediment Samples Collected
for Goodwin Creek Watershed (5/78 - 4/94)

Station	Fines Load	Total Sand Load
1	3628	2134
2	3642	2427
3	2524	751
4	3482	160
5	3709	585
6	2531	48
7	3313	338
8	2210	0
9	1446	59
10	1851	0
11	1516	0
12	2752	53
13	3022	1054
14	2791	50
Total	38,417	7,659

6.1.5 Gravel Samples

Transport of gravel has been sampled using modified Helley-Smith (MHS) samplers and Box samplers on Goodwin Creek. The MHS samples has been collected primarily at stations 1, 2 and 3, while Box samplers have been used to sample bed load at sites near stations 13 and 14. Collection of MHS samples begins at the center of the 'V' of each flume at intervals of 1.5 m up the right side (left side for flume 1) of the 1:5 sloping part of the structure till the water is not deep enough to sample or the junction to the 1:2 slope is reached. A disadvantage of using MHS samplers is the personnel needed for their operation. A minimum of two people are needed for each site. The type of runoff events that generally occur on Goodwin Creek means that sampling on the rising limb of the hydrograph is very difficult. Therefore, very few samples before peak stage have been collected with the MHS samplers (Table 6.4).

The Box samplers are automatic and collect data on accumulated load at 1-minute intervals until the box fills-up. This assures that the bed load is sampled on the rising side of the hydrograph. However, large or long storms will cause the box to fill-up before the end of the runoff event (Kuhnle,1991). By comparison, the number of samples collected by the Box sampler is much greater than that of the MHS samplers (Table 6.4).

Table 6.4 Summary of Bed Load Samples

Station Number	Sample Type	Estimated Number of Samples	Year Sampled
1	MHS	200	87,89,90,91,92,93
2	MHS	730	85,86,87,88,89,91,92,93
3	MHS	180	87,89
13	Box Sampler	2250	88,89
14	Box Sampler	3500	88,89,90,91

6.2 Total Load and Reliability

At the present time, total load has been calculated for station 2 for 1985-1988 (Kuhnle, Willis, and Bowie,1989). The above summary of data collected indicates that sand and fine load calculations could reasonably be made for stations 1, 3, 5 and 13. Bed load transport relations calculated for stations 1 and 3 may be poorly constrained because of the low numbers of samples collected at those locations. However, the relation from station 2 should be similar to those for 1 and 3 and should provide guidance as to the type of relations at sites 1 and 3. Total load could probably be calculated for these 5 stations of the watershed.

Questions have been raised as to the accuracy and reliability of the sediment sampling and analysis procedures. The sampling procedures used for the sand and fine sediment follow closely the recommendations given in "Field Manual for Research in Agricultural Hydrology" handbook no. 224. Pumping sampler data is usually very representative of cross-section concentrations of material less than 0.062 mm in diameter because this material will be quite uniformly distributed in a channel or gauging structure section, so that it does not matter where the sampler intake device is located. For material larger than 0.062 mm in diameter, pumping sampler error increases rapidly with particle size, regardless of the location of the intake nozzle. At the present time, no standard procedures for the collection of bed load samples exist. The sampling techniques used for the gravel material have been designed, however, to measure the large spatial and temporal variations in bed load transport. These techniques have been documented in several studies. It is our opinion at the NSL that the sediment loads calculated for the Goodwin Creek watershed compare favorably to sediment loads calculated for other locations published in the technical literature (Coleman,1982).

6.3 Bulk Bed Material

Prior to 1994, bed material sampling has been confined to the channels below station 3 on the main stem of Goodwin Creek. In the summer of 1994, a watershed wide channel bed material sampling program was undertaken. The material in most of the main stem and the major tributaries of the watershed was sampled. The reaches were defined as lengths of channel between major tributary junctions. The location of the 14 reaches which were sampled are presented in Figure 6.2 (see Appendix D, particle size distributions for each reach). Each reach was field identified before the sampling was started. Sub-samples were collected at 30 meter intervals from 2 to 4 with locations at each site depending on channel width. All sub-samples from each reach were photographed and composited before size analysis. At the completion of the size analysis, each reach was characterized by one size distribution (Table 6.5) with a complete size analysis for each reach in Appendix D.

Table 6.5 Distributions of Sand and Gravel for Selected Reaches in Goodwin Creek Watershed

Reach Number	Total Sample (grams)	Total Gravel (grams)	Percent Gravel	Total Sand (grams)	Percent Sand
1	64435.3	25832.7	40.1	38602.6	59.9
2	143920.9	68226.1	47.4	75694.8	52.6
3	126433.8	73362.5	58.0	53071.3	42.0
4	98926.4	63852.0	64.5	35074.4	35.5
5	59896.8	33732.2	56.3	26164.6	43.7
6	149515.2	96192.2	64.3	53323.0	35.7
7	111111.7	62525.3	56.3	48586.4	43.7
8	121701.9	52966.8	43.5	68735.1	56.5
9	72722.9	33709.9	46.4	39013.0	53.6
10	72366.7	46578.2	64.4	25788.5	35.6
11	69077.3	32943.5	47.7	36133.8	52.3
12	66921.3	19898.3	29.7	47023.0	70.3
13	67295.0	34653.3	51.5	32641.7	48.5
14	94871.6	61616.5	64.9	33255.1	35.1

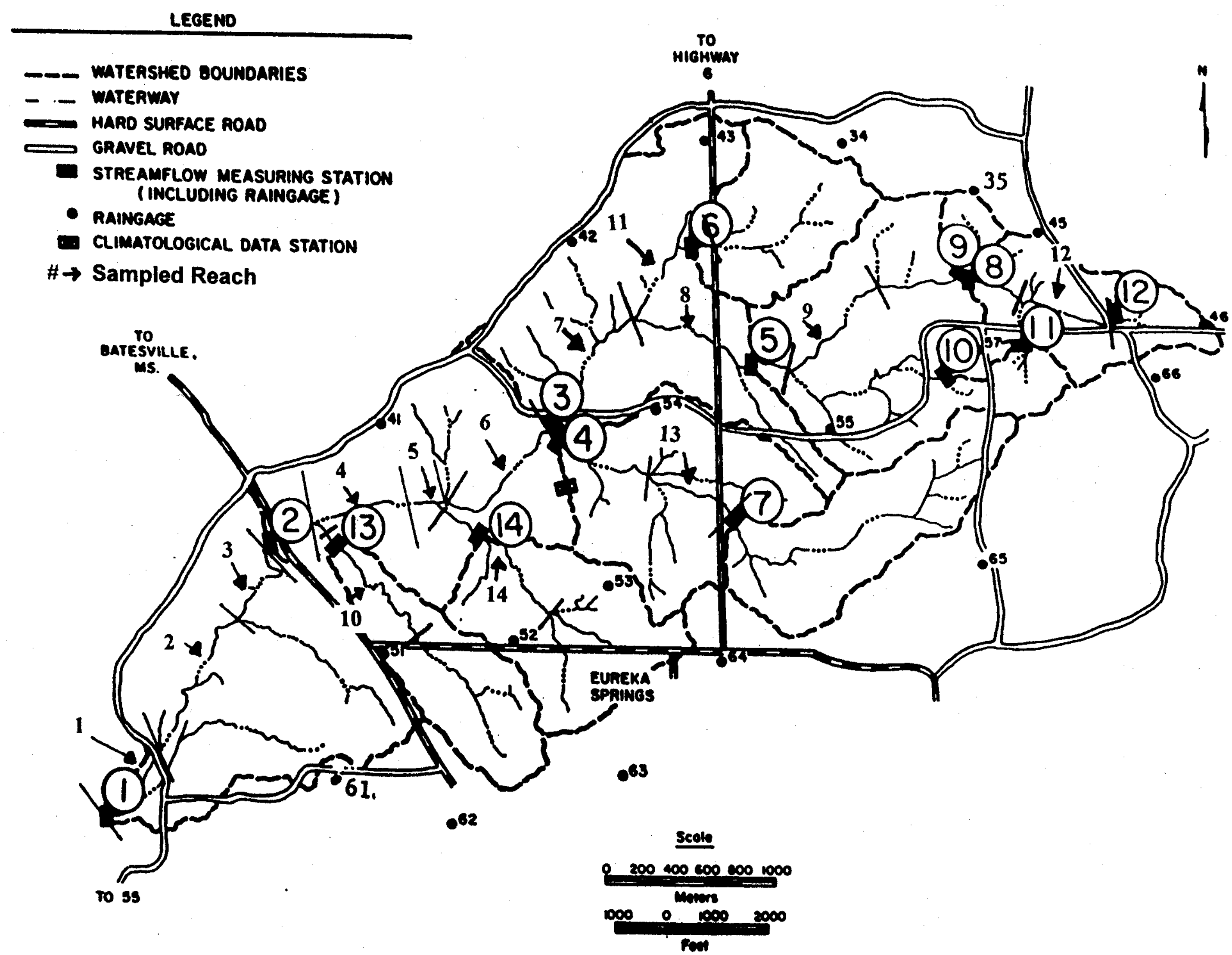


Figure 6.2 Location of Sampled Reaches in Goodwin Creek Watershed